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RADIATION.*

BY

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THOSE radiations which are commonly classed as wave-motions are characterized by the fact that they cannot be affected by the presence of an immaterial agent, such as an electrostatic or a magnetic field in their path. Radio waves, infra-red waves, visible light, ultra-violet light, X-rays and γ-rays are all commonly classed as wave motions and are usually considered to differ from each other only in "wave-length." Since these "waves" cannot be affected while traversing empty space, our whole knowledge of them is based upon experiments which deal either with the material substances in the source of the "waves" or with the material substances interposed in their path. For this reason, the study of these radiations really consists in a study of (A) the nature of the atoms of material substances and (B) of the interactions between these atoms and radiation. Many branches of physics and chemistry have contributed, directly or indirectly, to such study. It is the purpose of these articles to show what these contributions are, and how they are related to the general problem of radiation.

* Presented at a meeting held Thursday, January 31, 1924.

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(A) MATERIAL SUBSTANCES AS SOURCES OF RADIATION.

The experimental data dealing with the nature of matter and the way in which matter may act as a source of radiation fall naturally into two main groups: The first, containing data from experiments not directly connected with the emission or absorption of "waves," the second, containing the results of experiments on the emission of "wave motion" itself. As these two groups are studied, it will be seen that the pictures to which they give rise are such that they may be easily reconciled with each other to give a single picture which serves at present as a fairly satisfactory approximation to reality. The relation between the two pictures has been likened by D. L. Webster to the relation between the photograph of a man and his Bertillon measurements, in that one gives a qualitative idea of his appearance by which he can be easily recognized; the other offers a quantitative method by which he may be positively identified. The two groups of data will be taken up in the order given above.

CONSIDERATIONS BASED ON EXPERIMENTS WHICH DO NOT HAVE TO DO DIRECTLY WITH RADIATION.

The Atomic Nucleus.—It was shown by J. J. Thomson [1] that negative electricity occurred in discrete units. These units, or "electrons," seemed to be a component of all matter, and the electrons from one element acted in every way like those from any other element. In order to account for the fact that the atoms of the elements are electrically neutral, he assumed that there resided in each atom a charge of positive electricity equal to the sum of all the negative electricity represented by the electrons. Experiments by Rutherford [2] soon led to rather definite ideas in regard to the state of the positive charge. He found that alpha particles (positively charged helium atoms) could penetrate a few hundredths of a millimetre of metal foil with almost no loss of speed or change of direction. Those few which were turned back by the foil seemed to be reflected with but little loss of speed. This was consistent with the picture of a positive nucleus of extremely small volume surrounded by electrons which were relatively far away from the nucleus.

Although the small size of the nucleus seems necessary in order to account for the passage of the alpha particles through

the atom, there is another justification which is equally important. The mass in grams of the various atoms is known. It is 1.649×19^{-24} times the atomic weight. The mass of the electron is also known. It is 9.0×10^{-28} grams. There is good evidence for assuming that the number of electrons surrounding the nucleus is equal to the atomic number. It is at once evident that the electrons contribute only a small amount to the total mass of any atom. The mass must reside, therefore, largely in the nucleus. If we consider this mass to be electromagnetic in nature, it may be made large enough to account for its share of the observed mass of the atom by decreasing the radius of the nucleus. We therefore arrive at the same picture as before, namely, a positive nucleus of very minute size. The maximum possible size of a gold nucleus appears to be of the order of 10^{-12} cm., while that of the atom as a whole is of the order of 10^{-8} cm.

Aston's discovery [3] that the atomic weights of all elements, within experimental error, are whole numbers gives us a glimpse at the internal structure of the nucleus, for it makes it seem probable that atoms might be built up of H atoms, each composed of one electron and one unit of positive electricity. Now the atomic weight of He is 4.00. It would appear that He could be made up of four H atoms if we could account for the slight difference in mass. Four H nuclei require four electrons to produce a neutral atom. But, since the atomic number of He is 2, we assume that the atom is composed of a nucleus outside of which are two electrons. This means that the remaining two electrons must be in the nucleus itself. We, therefore, have a helium atom made up of (1) a positive nucleus containing four positive charges of electricity and two electrons and (2) two electrons outside of this nucleus. At first sight it would seem that the atomic weight of such an atom should be $4 \times 1.008 = 4.03$. It must be remembered, however, that just as two adjacent wires carrying current in opposite directions have less self-induction than one of the wires alone, so opposite charges of electricity in the same nucleus will have less mass than the positive charge alone. We must therefore imagine that the electrons in the nucleus are so spaced with respect to the positive charges as to bring the atomic weight down from 4.03 to 4.00.

Similarly any other atom of atomic number N may be pictured as being made up of (1) a nucleus composed of n electrons and m

positive charges (thus giving a net positive charge of $m-n$), and (2) a cluster of $m-n=N$ electrons arranged outside of the nucleus. Some nuclei may be pictured as being made up of clusters of He nuclei. For instance, O might be made up of four He atoms, the electrons of the He assuming the configuration characteristic of O. In this case the four He nuclei could not be packed together very closely, otherwise the mass of the O atom could not be exactly four times that of the He atom.

Such cases as *N* and *F*, where the atomic weight is in excess of that to be expected of an integral number of He atoms, might be accounted for by the proper packing of H and He nuclei if only we could find some way by which the nucleus could hold itself together against the mutual repulsions of its component positive charges. But after all this problem is not greatly different from the more general problem of how any nucleus, composed of positive charges, can be stable. If only we assume the proper degree of packing, the atomic weights of all atoms can be accounted for in terms of the weights of H and He.[4] This is the more easily done when we remember that most elements whose atomic weights are not ordinarily listed as integers are really mixtures of isotopes.[3, 5] From the above it is seen that our present picture of the atomic nucleus is a little indefinite and hazy. This is necessarily true because so few experimental facts are available upon which to base a picture.

The Static Atom from a Chemical Viewpoint.—The physical and chemical properties of the various elements offer a basis for a very definite picture or group of pictures of the arrangement of the electrons around the nucleus. If the elements are arranged in the order of their atomic numbers, it is at once evident that there is a periodic change in most of their chemical properties. These facts are brought out in the well-known Mendeléeff table. The periodic change in properties suggests a corresponding periodic change in the configuration of electrons in the atoms. Considerations of this sort led G. N. Lewis [6] to propose structures for the elements of low atomic number. This picture was later amplified by I. Langmuir [7] and extended to cover all the elements. A modified form has lately been proposed by M. Huggins.[8] At about the same time that Lewis proposed his original theory a somewhat similar structure was proposed by Born and Lande and Kossell.[9] The Lewis-Langmuir picture is perhaps the best known

of these, and may be regarded as typical of all structures based on the evidence of the Mendeléeff table. The periods of the table are composed of 2, 8, 8, 18, 18 and 32 elements, respectively. These numbers may be written $2(1)^2$, $2(2)^2$, $2(2)^2$, $2(3)^2$, $2(3)^2$, and $2(4)^2$, respectively. The factor 2 is taken to mean that all atoms tend to show symmetry about an equatorial plane. This symmetry is complete in the last member of each period, *i.e.*, in the inert gases, He, Ne, A, Kr, Xe, Nt. The electrons are considered to be arranged in "shells" about the nucleus. He is assigned a "shell" of only two electrons; Ne, an inner shell of two and an outer shell of eight; A, an inner shell of two, a shell of eight outside of this, and a third shell of eight beyond that. Kr is assigned four shells of 2, 8, 8, and 18 electrons, respectively; Xe, five shells of 2, 8, 8, 18 and 18, while Nt is given six shells of 2, 8, 8, 18, 18 and 32 electrons. The picture is extended to the other elements in such a way as to account satisfactorily for the valence and other chemical properties. For instance, the external structure of Na is pictured as differing from that of Ne in having one extra electron which resides outside of the Ne shell. This extra electron is more easily detached than any other, so that it is called the "valence electron." The detachment of this electron leaves a sodium ion with a single positive charge. Mg is supposed to have two such electrons; Al, three, and Si, four.

P is pictured as having five such electrons. If it loses all five, reverting to a structure like Ne, it has a valence of five as in PCl_5 or P_2O_5. If it gains three electrons, thus taking on the form of A, it has a valence of three as in PH_3.

Such a picture accounts not only for the chemical properties of the elements and their compounds, but also for quite a mass of physical properties, such as freezing points, boiling points, critical pressures, critical temperatures and even the color of certain compounds.

The most symmetrical arrangement of eight electrons is that in which the electrons occupy the corners of an imaginary cube, and in the Lewis-Langmuir picture the cubic "shape" of the light atoms is assumed. Since the publication of these theories, the cubic "shape" of these atoms has been verified in a rather unexpected way.[10] The X-ray diffraction pattern of crystals of the lighter alkali halides and of the oxides and sulphides of the lighter alkali earths show that the *ions* of these elements (which have

the same number of electrons as the *atoms* of the corresponding inert gases) pack as though they were cubes with well-rounded corners. It would therefore seem reasonable to assume that the atoms of the lighter inert gases had a similar "shape." The theory is confirmed in the case of the heavy elements in no less striking fashion. The Lewis-Langmuir theory gives Xe eighteen electrons in each of its two outmost shells. Such an atom would approximate a sphere rather than a cube. Experimentally it is found that Cs^+ and I^- (which have the same number of electrons as Xe) pack together in CsI to form a body-centred cubic structure. This structure is the closest possible packing for equal numbers of oppositely charged spheres of equal size. Furthermore, the dimensions of I^- determined from the crystals of its compounds [11] show the same "radius" in two directions about 54½ degrees apart. Such a result is inconceivable for any regular figure other than a sphere.

The Static Atom from a Physical Standpoint.—A picture of atomic structure which not only is consistent with so many experimental facts of both a chemical and a physical sort, but which also is able to predict the results of data on the "packing shape" of atoms and ions is a picture not to be cast aside without good reason. Strangely enough, what might at first sight appear to be its weakest point turns out to be its point of greatest strength. A simple calculation shows that eight electrons cannot be held out in space at the corners of an imaginary cube against the attractive force of eight positive charges on the nucleus if Coulomb's law is assumed to hold for intra-atomic distances. Obviously, if we are to retain the picture, we must choose one of three alternatives: (1) We must consider the electrons to be so large as to touch each other in the atom, or (2) we must hypothecate such a structure to the nucleus as will produce a non-uniform field of force in the atom, or (3) we must assume a modification of Coulomb's law for small distances.

The first alternative can hardly be accepted in the light of existing experimental data. Crystal structure studies show that the atoms of metals and the ions of "ionic" compounds pack in crystals like rubber balls of one shape or another in contact with each other.[11, 12] If these atoms and ions are composed of electrons in contact with each other like the corns on a pop-corn ball, the only path possible for alpha particles would be the natural

voids in the crystal. In such a case, the stopping power of a substance should depend upon the crystal structure of the absorber and upon the orientation of the crystals. Now the stopping power of three crystalline substances is known, namely, Al, Ag, and Pt.[13] All three of these crystallize as face-centred cubes, so that the useful portion of a given crystal face is the same for all three. All three were used in the experiment in the form of thin foil. Recent work seems to show that rolling such metals into foil tends to give the crystals a definite orientation which is a characteristic of the crystal structure rather than of the metal used. This means that, if the pop-corn ball structure is correct, all three metals should have the same stopping power. Instead, experiment shows that the stopping power of elements is proportional to the square root of the atomic weight. In the case of compounds, the stopping power is proportional to the square root of the molecular weight. Apparently the stopping power shows no simple relation to the atomic number. We have seen that the mass of an atom is primarily due to its nucleus, while the atomic number has to do with the number of electrons in the atom. Evidently then, the stopping power of an atom on an alpha particle is primarily a property of its nucleus, and not of its electrons. This would seem to require an atomic architecture quite different from the pop-corn ball type.

Our second alternative is to assume a nuclear structure, such that in certain directions the attractive force of the nucleus on any given electron will be decreased. If the shape of such a field of force could be made such as to enable electrons to find positions of stable equilibrium, the problem would be solved. But as soon as we have admitted that in certain definite directions the attractive force between the nucleus and an electron may be less than that required by Coulomb's law, we are dealing with a special case of the third possible alternative. We will therefore pass at once to a consideration of that alternative. It will be seen that this alternative presents many attractive features which make it worthy of considerable attention.

The most obvious modification of Coulomb's law would be to superimpose upon the inverse square law a sine or cosine law with a decrement. If the decrement were large enough to leave only the inverse square law at points outside the atom, the modified law would satisfy all existing experimental data. A simpler

modification, and one which lends itself more readily to numerical calculation, is to assume that the force of attraction follows the equation:

$$F = Ee\left(\frac{1}{r^2} - \frac{c}{r^3}\right). \tag{1}$$

This gives only one point of inflection in the graph of the law, and degenerates into the ordinary law at a distance determined by the constant c.

This law of force between the electron and the nucleus has been investigated by J. J. Thomson with remarkable results.[14] It is found that those configurations of electrons which are stable under such a law show a periodicity corresponding to that of the Mendeléeff table, so that the various chemical properties are satisfied. It is found possible to derive the law of ionizing potentials of the simpler atoms such as Li, Be, N and O. In the case of the alkali metals it is possible to find the frequency of the light to which each is photo-electrically active. Even the compressibility of these metals can be calculated.

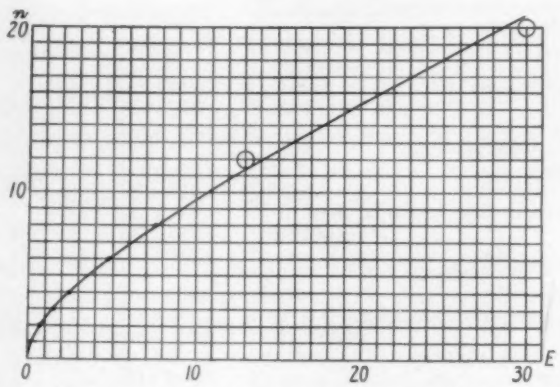
The correspondence between the various calculated values and the experimental results is such as to give considerable of a feeling of confidence in the picture of atomic structure upon which the calculations are based. It will therefore be worth our while to reproduce these calculations. The method of derivation is taken directly from Thomson's published work with only a few minor changes, most of which are made necessary by the crystal structure of the alkali metals as determined by X-ray diffraction experiments. In every case these corrections give calculated results which agree with the experimental data even better than did Thomson's original values.

Configurations of Electrons.—In Fig. 1 are plotted the number of electrons, n, which can be held in a single three-dimensional symmetrical shell by a nuclear charge E measured as a multiple of e, on the assumption that equation (1) is valid. The data are taken from Thomson's book "The Electron in Chemistry." It is seen that if the nuclear charge is 6 or less the atom is so stable that it could even hold one extra electron, thus becoming negatively charged. Such negatively charged ions have been observed experimentally in the case of H, C, and O. A nuclear charge of 8 is stable with eight electrons but not with nine. Nine electrons are apparently just barely unstable in a single shell surrounding a

nuclear charge of 9. It can be shown, however, that if these nine electrons are arranged to form a shell of eight with one electron outside this shell, then they will all be in stable equilibrium with a central nuclear charge of 9.

Such an atom would resemble in its external characteristics the atom containing only one electron and it is evident that we have the germ of a periodic system of the elements. But if we compare these results with the Mendeléeff table, we find that the first group, ending in He, is not one of eight, but one of two elements. It is the second group, ending in Ar, which contains eight

FIG. 1.



Graph of J. J. Thomson's calculations on atomic stability.

elements. We must therefore re-interpret our calculations so that n in Fig. 1 means, not the total number of electrons outside the nucleus, but this number minus two. E can, therefore, not represent the total nuclear charge, but instead it is this charge less two. In reading Thomson's papers on this subject it is necessary to remember that he confines his attention exclusively to the outmost layer of electrons so that no mention is made of this pair near the nucleus nor of any other shells which may be between this pair and the outmost layer. If this is borne in mind, it is seen that this picture, obtained from the law of force assumed in equation (1) is much like that of the Lewis-Langmuir theory in which, as we pass from one element to the next, we picture two electrons held near the nucleus, then beyond these two a shell which is complete with eight electrons, then another shell which is complete with

eight more electrons, etc. We therefore have an atomic architecture which rests not only upon a mass of chemical evidence but which, in terms of equation (1), satisfies the conditions of physical stability.

In the description of the Lewis-Langmuir theory it was stated

TABLE I.

Potential Energy of Atoms with Three to Eight Electrons.
(Thomson and Woodward)

Arrangement of Electrons.	Distances of Electrons from Atom.	Potential Energy.
Eight electrons.		
(i) One layer—twisted cube	1.447 c	$-16.75\ e^2/c$
(ii) One layer—cube	1.446 c	$-15.28\ e^2/c$
(iii) Two layers—tetrahedra similarly orientated	1.105 c (4) 3.108 c (4)	$-14.77\ e^2/c$
(iv) Two layers—six electrons in inner, two in outer ring	1.282 c (4) 1.267 c (2) 4.80 c (2)	$-15.012\ e^2/c$
Seven electrons.		
(i) One layer	1.37 c (2) 1.439 c (5)	$-12.181\ e^2/c$
(ii) Two layers—five in inner, two in outer ring	1.244 c (3) 1.191 c (2) 4.316 c (2)	$-12.096\ e^2/c$
Six electrons.		
(i) One layer	1.385 c	
(ii) Two layers—four in inner, two in outer ring	1.196 c (4) 3.55 c (2)	$-9.40\ e^2/c$ $-8.868\ e^2/c$
Five electrons.		
(i) One layer	1.342 c (3) 1.376 c (2)	$-6.806\ e^2/c$
(ii) Two layers—four in inner, one in outer ring	1.273 c (3) 1.134 c (1) 5.105 c (1)	$-6.667\ e^2/c$
Four electrons.		
(i) One layer—corners of square	1.298 c	$-4.748\ e^2/c$
Three electrons.		
(i) One layer—equilateral triangle	1.238 c	$-2.934\ e^2/c$
(ii) Electrons on a straight line through atom	1.087 c 1.035 c 3.577 c	$-2.787\ e^2/c$

that the lighter inert gases were considered to be cubical in shape and experimental evidence was given to show that such atoms acted like cubes with well-rounded corners. Thomson gives a table calculated by Miss Woodward,[14] in which is shown the potential energy of this and alternative arrangements for atoms containing from three to eight electrons (not counting the pair near the nucleus). This table is reproduced in Table I. It shows

that from an energy standpoint there is little choice between the alternative configurations. Only slight variations in equation (1) would be necessary to make any one of the alternatives show the minimum potential energy. The twisted cube fits some of the chemical data even better than the regular cube. It is not quite consistent with the crystallographic data mentioned above.

Ionizing Potentials of Static Atoms.—The act of ionization consists in the removal of an electron from an atom. Let us assume that this electron is removed so suddenly that the rest of the electrons in the atom do not have time to change their positions by any appreciable amount until after the ejected electron has passed beyond their "range of action." The energy involved comes from two sources. The work done in removing the electron against the attraction of the positive charge in the nucleus is

$$(2) \qquad E\varepsilon\left(\frac{1}{r}-\frac{1}{2}\frac{c}{r^2}\right).$$

The work done by the other electrons in the atom in aiding the removal is

$$(3) \qquad \frac{e^2}{r_{12}}+\frac{e^2}{r_{13}}+\frac{e^2}{r_{14}}+\cdots\cdots\cdots$$

where r_{12}, r_{13}, r_{14}, etc., are the distances before ejection occurs between electron 1 and electrons 2, 3, 4, etc. Now if $2\theta_{12}$, $2\theta_{13}$, etc., are the angles formed by the radii from the nucleus to electrons 1 and 2, 1 and 3, etc., then

$$r_{12}=2r\sin\theta_{12}$$
$$r_{13}=2r\sin\theta_{13}$$
$$\text{etc.}$$

where r is the distance from an electron to the nucleus. This involves the assumption that all the electrons are equidistant from the nucleus. This assumption is not necessarily true, but it enables us to easily calculate results which may be sufficiently approximate. Equation (3) may therefore be written

$$(4) \qquad \frac{e^2}{2r}\left(\frac{1}{\sin\theta_{12}}+\frac{1}{\sin\theta_{13}}+\frac{1}{\sin\theta_{14}}+\cdots\cdots\cdots\right)$$
$$=\frac{e^2}{2r}S_n$$

The net work from an external source required to suddenly eject the electron is, therefore,

$$(5) \qquad E\varepsilon\left(\frac{1}{r}-\frac{1}{2}\frac{c}{r^2}\right)-\frac{e^2}{2r}S_n.$$

Now the condition of equilibrium in the atom is that the attraction between an electron and the nucleus must be balanced by the repulsion between the electrons. That is

$$Ee\left(\frac{1}{r^2}-\frac{c}{r^3}\right)=\frac{e^2}{(2r\sin\theta)^2}\sin\theta=\frac{e^2}{4r^2}S_n. \tag{6}$$

This gives a value of c which may be substituted in equation (5). If the ionizing potential is V, then the work of ionization Ve is

$$Ve=\frac{Ee}{2r}-\frac{3}{8}\frac{e^2}{r}S_n. \tag{7}$$

Since E is equal numerically to the atomic number, N, times e, we may write

$$V=\frac{e}{2r}\left(N-\frac{3}{4}S_n\right). \tag{8}$$

Any attempt to make equation (1) degenerate more quickly to Coulomb's law, as by introducing a decrement into the r^3 term, will increase the work which must be done against the attractive force of the nucleus, and will therefore raise the value of V.

It is evident, from the method of derivation, that equation (8) is strictly applicable only to those light atoms which have all their electrons within a single shell, *i.e.*, H and He. If we assume that the inmost pair of electrons lies so close to the nucleus that the net effect is merely to reduce the effective nuclear charge, we may apply the equation as a first approximation to the atoms from Li to F. If we assume, further, that the second shell is very close to the nucleus in comparison with the third shell, the equation may be applied as an approximation for elements from Na to Cl, etc. Now the ionizing potentials calculated from equation (2) for atoms, having from one to seven electrons in the outmost shell, are given in Table II. This table shows that the ionizing potentials are practically inversely proportional to the radii of the atoms. We therefore have the same law that was proposed by Eve [15] from a consideration of ionization potential data and Bragg's estimate [16] of atomic radii. The same law was used by Saha [17] as a method of calculating atomic radii.

We cannot calculate the ionizing potential directly from the formulas of Table II, for we do not know the distance of the electrons from the centre of the atom. It is possible, however, to make a satisfactory test of the essential correctness of these formulas, for the "packing radii" of many atoms are known.

X-ray diffraction data show that atoms pack in crystals like hard balls. In many cases the marshalling of atoms is such as would be expected of spheres. In other cases it is what would be expected of ellipsoids of revolution.[18] The "packing radius" of an atom is the radius of the equivalent sphere or spheroid in the crystal of the element. This "packing radius" must depend in

TABLE II.

Dependence of Ionizing Potentials on Atomic Radii, as Calculated from Equation (8).

Number of Electrons in Outmost Shell.	Ionizing Potential for Quick Ionization.
1	$.50\ e/r_1$
2	$.625\ e/r_2$
3	$.633\ e/r_3$
4	$.63\ e/r_4$
5	$.54\ e/r_5$
6	$.52\ e/r_6$
7	$.50\ e/r_7$

some way upon the distance of the outmost electrons from the nucleus, *i.e.*, upon the actual radius. If we assume that the "packing radius" is proportional to the actual radius, we may write

$$I.P. = K\frac{e}{r_p} \tag{9}$$

where r_p is the packing radius. This equation should then hold to within the degree of approximation to which equation (8) holds.

In the case of the monovalent elements we can feel sure that ionization can only mean the ejection or reception of a single electron. Our approximate law may therefore be expected to apply. The second column of Table III gives the packing radii

TABLE III.

Relation between Experimental Values of Ionizing Potentials and Atomic Radii as Determined by X-ray Methods.

Element.	Packing Radius of Atom.	Ionizing Potential.	$R \times (I.P.)$
Li	1.51	5.37	8.1
Na	1.86	5.13	9.5
K	2.25	4.1	9.2
Cl	1.08	8.2	8.9

of the only monovalent elements whose radii have been determined by X-ray diffraction methods. They are Li,[18] Na,[18] K [19] and Cl.[20] The ionization voltages in the third column are from a table by Foote and Mohler.[21] The fourth column shows how approximately equation (9) holds true. It is therefore a measure of the correctness of equation (8).

If the valence electron of an alkali metal is removed, thus producing an alkali ion, then the value of S_n in equation (8) is the same as if we were dealing with one of the electrons of the complete shell itself, and r becomes the radius of the complete shell rather than the distance from the nucleus to the valence electron. Now let us assume that the radius of the outmost complete shell is proportional to the packing radius of the alkali ion. If, then, our reasoning is correct, equation (8) indicates that the packing radii of the alkali ions should be roughly inversely proportional to the ionizing potentials of the corresponding atoms.

TABLE IV.

Relation between Experimental Values of Ionizing Potentials and Ionic Radii as Determined by X-ray Methods.

Element.	Packing Radius of Ion.	Ionizing Potential.	$R \times (I.P.)$
Na	1.1–1.2	5.13	56–62
K	1.55	4.1	64
Rb	1.68	4.1	69
Cs	1.97	3.9	77

Recently the packing radii of these ions have been determined[20] with considerable accuracy by X-ray diffraction methods. In Table IV these radii are compared with the corresponding ionizing potentials. The last columns of Tables III and IV are excellent support of equation (8) and of the picture on which the equation is founded. The original application of equation (8) to *atomic* radii made no distinction between the ionization of positive and negative elements. There is, however, no reason why the application to *ionic* radii should hold for negative ions.

The Photo-electric Effect.—The photo-electric effect is most marked in the alkali metals. The crystal structure of three (Li, Na and K) is known to be body-centred cubic [18, 19] at low temperatures. Hull has shown [22] that elements in the same vertical column of the Mendeléeff table show a remarkable similarity in

crystal structure. We will therefore assume in our calculations that Rb and Cs have the same crystal structure as Li, Na, and K. It will be shown later that, in terms of the end-results, this assumption is not essential.

By an ingenious method Thomson [14] has been able to calculate the potential energy of the valence electron of a monovalent metal on the assumption of a simple cubic crystal structure. He has extended this to the face-centred cubic structure and Miss Woodward has calculated the corresponding values for the body-centred cubic arrangement. Using these values, we will calculate the work required to pull the valence electron out from the atom (a) if the crystal is simple cubic, and (b) if it is body-centred cubic.

If we assume the simple cubic structure, we may imagine the valence electron occupying the centre of each cubic "cell." This " cell " is the same as the " unit-crystal " of modern X-ray crystallography. For such an arrangement, Thomson finds a potential energy of $1.825\,\frac{e^2}{2d}$ for each cell, where $2d$ is the side of the unit cube. Since $2d = \left(\frac{\text{mass of the atom}}{\text{density}}\right)^{1/3} = \left(\frac{M}{D}\right)^{1/3}$ we may write

$$P.E. = -1.825e^2\left(\frac{D}{M}\right)^{1/3} \tag{10}$$

Now the mass of an atom in grams is 1.649×10^{-24} times its atomic weight,[23] so that we have

$$P.E. = -1.545e^2\left(\frac{D}{M'}\right)^{1/3} \times 10^8 \tag{11}$$

where M' is the atomic weight. This potential energy is equal to the energy of an electron falling through a drop of

$$22.1\left(\frac{D}{M'}\right)^{1/3} \text{ volts.}$$

The values for the various alkali metals are given in Table V.

Now if W_1 is the work required to expel an electron from the cell, and if W_2 is the work required to expel a metallic ion from the cell, then

$$P.E. = \frac{1}{2}(W_1 + W_2). \tag{12}$$

Assume that W_1 is a constant fraction of the total energy, *i.e.*,

$$W_1 = a(P.E.) = \frac{a}{2}(W_1 + W_2).$$

The difference in W_1 for sodium and for potassium is the contact difference of potential for these metals. Then from Table V this contact difference of potential is

$$a \times 7.70 - a \times 6.22 = 1.48a \text{ volts.}$$

Experimentally it is 0.4 volt, so that a is 0.27. This means that in order to find the work required to ionize an atom in a cell in

TABLE V.

P. E./e of a Unit Crystal of Alkali Metal.

Element.	D	M'	$\left(\frac{D}{M'}\right)^{\frac{1}{3}}$	$\frac{P.E.}{e}$ for Simple Cube.	$\frac{P.E.}{e}$ for Body-centred Cube.
Li	.534	7.	.424	9.38^v	16.4^v
Na	.971	23.	.348	7.70	13.5
K	.862	39.	.281	6.22	10.9
Rb	1.532	85.5	.262	5.80	10.2
Cs	1.87	132.	.242	5.36	9.4

the body of an alkali metal (assuming a simple cubic structure) we must multiply the values of Table V by 0.27. This gives

Li -2.54 volts
Na -2.08
K -1.68
Rb -1.58
Cs -1.45

No cases are known experimentally of elements crystallizing as simple cubes. The alkali metals, as stated above, crystallize as body-centred cubes, at least at low temperatures. Assuming a highly probable configuration of electrons Miss Woodward calculated that the potential energy of a body-centred monovalent metal is

$$P.E. = -\frac{4.03e^2}{2d}. \tag{13}$$

The arrangement of electrons is arrived at as follows: Of the possible symmetrical arrangements of two electrons in a body-centred cube of positively charged ions, the arrangement which is most stable electrically is that in which the electrons are placed on one of the body-diagonals of the cube, one-quarter of the length of the diagonal in from each end. Since there is a positive ion at each cube-corner and one at the cube-centre, this places an

electron midway between the ion at the cube-centre and the ion at one of the cube-corners. In order to preserve without distortion the cubic structure of the crystal as found by X-ray diffraction methods, it is necessary to assume that adjacent cubes have their electrons on different body-diagonals, so that of four adjacent cubes having a common edge, no two have electrons on intersecting or parallel diagonals.

Since each "unit-crystal" of a body-centred cube contains two atoms, $2d = \left(\frac{2M}{D}\right)^{1/3}$ and

$$P.E. = -4.03e^2\left(\frac{D}{2M}\right)^{1/3} = -2.71e^2\left(\frac{D}{M'}\right)^{1/3} \times 10^8. \tag{14}$$

This is therefore the energy of an electron falling through a drop of $38.8\left(\frac{D}{M'}\right)^{1/3}$ volts. The values for the various alkali metals are given in Table V. The contact difference of potential between sodium and potassium is therefore

$$a\,(13.5 - 10.9) = 2.6a = 0.4 \text{ volt}$$
$$a = .15$$

Therefore the work required to ionize an atom from a cell in the body of an alkali metal

Li —2.46 volts
Na —2.03
K —1.63
Rb —1.53
Cs —1.41

These values are almost identical with those calculated on the basis of the simple cubic structure.

It is hard to determine experimentally what is the longest wave-length to which a given metal is photo-electric, because for these limiting wave-lengths the intensity of the photo-electric effect is very small. Curves of data on the variation of intensity of the photo-electric effect with the wave-length of the exciting light are available [24] for Li, Na and K.

Of these, the shape of the curves for Li and Na is given with some detail. Results taken from these curves are compared in Table VI with the results calculated above. That the values from the curves are only approximate is well shown by the fact that

my reading for the quantum voltage from the graph for sodium is 2.03, while Richardson estimates 2.1 volts from the photo-electric effect and 2.6 volts from the thermionic effect.

Data are easily available [24, 25] on the wave-length to which each of the alkali metals shows a maximum photo-electric effect.

TABLE VI.

Calculated and Experimental Values for Maximum Wave-length which will Produce a Photo-electric Effect.

Element.	Calculated Minimum Voltage to Liberate Electron.	Maximum λ for Photo-electric Effect, Calculated from Quantum Relation.	Maximum λ for Photo-electric Effect from Experiment.	Ratio.
Li	2.46	5000	4500	1.11
Na	2.03	6100	5500	1.11

If our voltages as calculated above are correct, we might expect them to be a constant fraction of the quantum voltage corresponding to the maximum photo-electric effect. That this is so is shown in Table VII.

TABLE VII.

Constancy of Ratio between Calculated Maximum Wave-length for the Photo-electric Effect and the Experimental Wave-length for Maximum Photo-electric Effect.

Element.	Calculated Minimum Voltage to Liberate an Electron.	Calculated Maximum λ for Photo-electric Effect.	Experimental λ for Maximum Photo-electric Effect.	Ratio.
Li	2.46	5000×10^{-8} cm.	2800	.56
Na	2.03	6100	3400	.56
K	1.63	7600	4400	.58
Rb	1.53	8100	4800	.59

Compressibility of Metals.—As before we will take the potential energy of a body-centred cubic cell as

$$P.E. = -\frac{4.03}{2d}e^2.$$

If N is the number of cells per cubic centimetre, the energy per c.c. is

$$P.E. = -4.03\frac{Ne^2}{2d}$$

or

$$P.E. = -4.03\,N^{4/3}e^2. \tag{15}$$

Now if M is the mass of an atom, since there are two atoms per body-centred cube,

$$2NM = D \tag{16}$$

where D is the density of the element.

Therefore

$$P.E. = -4.03\left(\frac{D}{2M}\right)^{4/3}e^2. \tag{17}$$

The work required to compress the cells so that the side of the cell is changed from $2d$ to $2(d-\delta d)$ is

$$W = 4.03\frac{Ne^2}{2d}\left(\frac{\delta d}{d}\right)^2 = 4.03\left(\frac{D}{2M}\right)^{4/3}e^2\left(\frac{\delta d}{d}\right)^2 \tag{18}$$

Since

$$\frac{\delta d}{d} = \frac{1}{3}\frac{dV}{V},$$

$$W = \frac{4.03}{9}\left(\frac{D}{2M}\right)^{4/3}e^2\left(\frac{dV}{V}\right)^2. \tag{19}$$

But the bulk modulus, k, is defined by the equation

$$W = \frac{1}{2}k\left(\frac{dV}{V}\right)^2 \tag{20}$$

so that

$$k = \frac{8.06}{9}\left(\frac{D}{2M}\right)^{4/3}e^2 = \frac{3.20}{9}\left(\frac{D}{M}\right)^{4/3}e^2 = 4.16\left(\frac{D}{M}\right)^{4/3}\times 10^{12} \tag{21}$$

where M is the atomic weight and $1/k$ is the compressibility.

Table VIII gives the calculated values for k from equation (21), the corresponding values calculated on the basis of a simple cubic structure, and the experimental values due to Professor Richards. As in the case of the photo-electric effect, both sets of calculated values are nearly alike. The total deviation from the experimental values is a little less in the case of the body-centred structure which, it will be remembered, was the structure actually found by X-ray diffraction methods at those temperatures at which the alkali metals are crystalline.

Thomson has made a similar calculation for a face-centred cubic structure and finds that a simple symmetrical arrangement of

valence electrons is possible which gives ionizing potentials and compressibilities very close to those calculated above for the simple cubic and body-centred cubic structures. This may be taken to mean that, if the valence electrons are properly placed with respect to the rest of the atom, the potential energy per atom of a monovalent element is nearly independent of its crystal structure.

TABLE VIII.

Bulk Modulus of the Alkali Metals.

Element.	D	M'	Bulk Modulus k Calculated for Simple Cube.	k Calculated for Body-centred Cube.	k Experimental.
Li	.534	7.	$.154 \times 10^{12}$	$.135 \times 10^{12}$	$.114 \times 10^{12}$
Na	.971	23.	.068	.060	.065
K	.862	39.	.030	.026	.032
Rb	1.532	85.5	.022	.019	.025
Cs	1.87	132.	.016	.014	.016

We are therefore justified in including Rb and Cs in our calculations, even though their crystal structure is not known. From this we should expect our calculated values to be approximately correct even at those temperatures at which these metals are amorphous. In fact, the experimental values of the photoelectric effect and compressibility given in Tables VI, VII and VIII were obtained from what was in all probability amorphous metal.

The agreement between the experimental and the calculated values of compressibility is not limited to monovalent metals.

TABLE IX.

Compressibility of Polyvalent Elements.

Element.	Valence.	Calculated Compressibility (Thomson).	Experimental Compressibility.
Ca	2	5.2×10^{-12}	5.5×10^{-12}
Al	3	1.08	.75
C	4	.178	.16

Table IX compares Thomson's calculated values for Ca, Al and C with the experimental values.

To summarize, it has been shown that a law of force of the type necessary to stabilize a "static" atom makes it possible

(1) to deduce the law relating the atomic dimensions to ionizing potentials, (2) to calculate the ionizing potentials of various elements, and (3) to calculate their compressibilities. It remains only to show that this same law of force will enable us to calculate the spectra of the elements. It can be shown [26] that such calculations can be made from the law, but since such a discussion can be made more complete after we have taken up the Bohr atom, we will postpone it until that time. In the meantime, we will leave the "static" atom for a while, remembering that it gives us a picture which correlates an enormous mass of physical and chemical data, much of it quantitative, which is capable even of predicting the complete spectrum of such simple elements as H and He if we only assume the proper constant in Thomson's law of force between the electrons and the nucleus.

CONSIDERATIONS BASED ON EXPERIMENTS WHICH HAVE TO DO DIRECTLY WITH RADIATION.

Black-body Radiation.[27]—Imagine a tube with the ends plugged tightly and with only a small peep-hole through which the condition of the interior may be observed. Let the area of the hole be very small in comparison with the total area of the box so that the loss of radiation through the hole is negligibly small. It is found experimentally that the radiation in the interior of such a box depends upon the temperature, but not upon the material of which the box is composed, provided that the material is "black." For any given temperature there is some one frequency of radiation which is most intense. The intensity of frequencies smaller than this decreases asymtotically to zero. The intensity of frequencies greater than this drops off rapidly, becoming zero at a limiting frequency which is determined by the temperature.

A typical graph of intensity plotted against wave-length is given in Fig. 2. There have been three noteworthy attempts to express this sort of graph by formulas. The first is by Rayleigh:

$$E_\lambda = \frac{ckT}{\lambda^{-4}} \tag{22}$$

$$E_\nu = \frac{k\nu^2 T}{c^3} \tag{23}$$

where E_λ is the intensity of radiation of "wave-length" between λ and $\lambda + d\lambda$, and where E_ν is the intensity of radiation whose

frequency lies between ν and $\nu + d\nu$. T is the absolute temperature; c, the velocity of light, and k, a constant. The formulas agree well with the experimental graph only if λT is large.

The second attempt was made by Wien:

$$E_\lambda = \frac{c^2 h}{\lambda^5} \cdot \frac{1}{\varepsilon^{\frac{ch}{k\lambda T}}} \tag{24}$$

$$E_\nu = \frac{h\nu^3}{c^2} \cdot \frac{1}{\varepsilon^{\frac{h\nu}{kT}}} \tag{25}$$

where ε is the base of natural logarithms and h is a constant. These formulas agree with the experimental graph only when λT is small.

The third pair of formulas is by Planck:

$$E_\lambda = \frac{c^2 h}{\lambda^5} \cdot \frac{1}{\varepsilon^{\frac{ch}{k\lambda T}} - 1} \tag{26}$$

$$E_\nu = \frac{h\nu^3}{c^2} \cdot \frac{1}{\varepsilon^{\frac{h\nu}{kT}} - 1}. \tag{27}$$

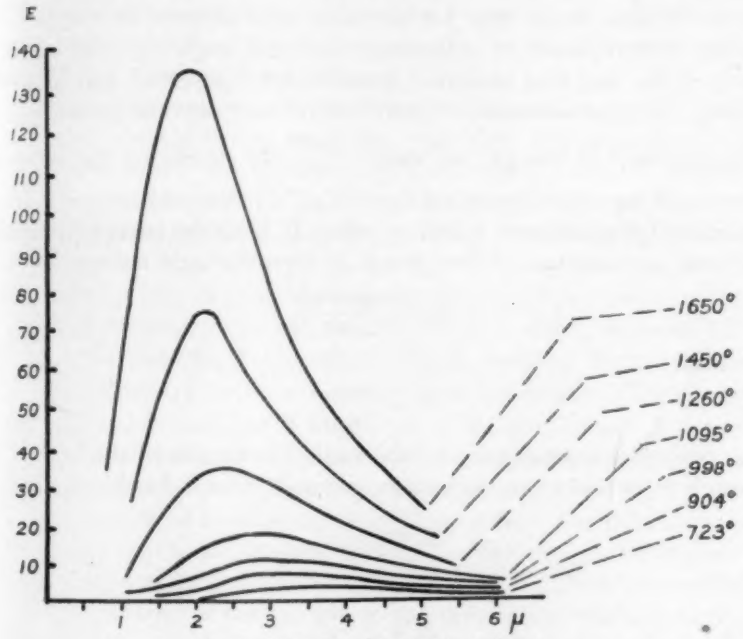
These last formulas agree with the experimental graph throughout its whole length. It will be worth our while to examine the three pairs of equations more closely.

Rayleigh's Theory.—Let us assume a cubical box made of perfectly reflecting material, and let this box contain a very tiny particle of matter at some definite temperature. Then after equilibrium has been reached, we might expect that the original energy of the atoms of the particle would, on the average, be equally distributed between the degrees of freedom of the several atoms of this particle and such degrees of freedom as might exist in the radiation in the box. This would give an equation containing two sets of terms, one dealing with the energy in the atoms, the other dealing with the energy in the radiation. Since the atoms have three degrees of freedom, the number of terms in the first class will be three times the number of atoms in the material particle. Each of these terms will therefore be equal to $\frac{1}{3}\alpha T$ where α is the universal constant which gives the ratio of the energy of an atom to its absolute temperature T.

It would seem at first sight that there should be an infinite number of terms of the second sort because there are an infinite number of frequencies in the radiation. But if experiments on

the spectrum as observed through a peep-hole apply here at all, they would indicate that the energy for any given frequency was not necessarily an "independent form of radiation." The ratio between the total radiant energy and the energy for a frequency between ν and $\nu + d\nu$, as determined through the peep-hole, is determined by the temperature of the material particle. In terms

FIG. 2.



Graph of intensity of black-body radiation.

of the radiation alone, it is determined by the maximum frequency present in the radiation.

The number of "terms of the second sort" may, however, be determined as follows: The only frequencies which can persist in a box such as we have assumed, without any peep-hole, are those capable of forming standing waves in the box. If the side of the box is 1 and if the frequencies of the various standing waves are considered to be independent of each other, then these frequencies are defined by

$$\nu = \frac{c}{2l}\left(p^2 + q^2 + r^2\right)^{1/2} \tag{28}$$

where c is the velocity of light and p, q, and r are any integers. For frequencies between ν and $\nu + d\nu$ the number of "terms of the second sort" will depend upon how many sets of integers can be used for p, q, and r and still permit equation (28) to have values between ν and $\nu + d\nu$. The number of these sets of integers is $\frac{4\pi\nu^2\beta^3}{c^3}\,d\nu$ if the side of the box is large compared with the wave-lengths of the radiation. The actual number of terms of this sort is really four times this, for we must take account of the possibility of two planes of polarization at right angles to each other, and of the fact that radiation contains both potential and kinetic energy in equal amounts. Therefore, if we grant the principle of equipartition of energy, we have $\frac{16\pi\nu^2\beta^3}{c^3}\,d\nu$ terms of the second sort each representing an energy $^1/_3\alpha T$ for the radiation of frequencies lying between ν and $\nu + d\nu$. If U_ν is the energy per unit volume of radiation of frequency, ν, then the total energy is

$$U_\nu\beta^3 = \frac{16\pi\nu^2\beta^3\alpha T}{3c^3}$$

so that

$$U_\nu = \frac{16\pi\nu^2\alpha T}{3c^3} \tag{29}$$

Since the intensity E_ν of the radiation measured through the peep-hole is related to the energy per unit volume by the equation

$$E_\nu = {}^c/_{8\pi}\, U_\nu$$

we have

$$E_\nu = \frac{2}{3}\,\frac{\alpha\nu^2 T}{c^2} \tag{30}$$

This equation is identical with (23) if $k = {}^2/_3\alpha$.

Now the value of α can be calculated from the compressibility of a "perfect" gas like hydrogen and the Loschmidt constant as follows: The kinetic theory of gases shows that

$$pv = \frac{2}{3}\,\alpha n T \tag{31}$$

where p and v are, respectively, the pressure and volume and n is the number of molecules per gram-molecule; n can be calculated at once from the Faraday constant and the charge on the electron. The liberation of a gram-molecule of silver or iodine by electrolysis requires 96,500 absolute coulombs.[28] Since each ion of

silver or iodine requires the passage of one electron to change it to an atom, the number of atoms per gram-molecule is [29]

$$n = \frac{96{,}500}{1.591 \times 10^{-19}} = 6.065 \times 10^{23}$$

At 0° C. (= 273.1° K.) and a pressure of one atmosphere (1.0132×10^6 dynes per square centimetre) the volume of one gram-molecule of hydrogen is 2.2412×10^4 c.c. Equation (31) therefore gives 2.058×10^{-16} as the value of α. This gives 1.371×10^{-16} as the value of k in equation (23). Experimentally the value of k is 1.346×10^{-16}.

In contrast with this excellent agreement between the calculated and experimental values, we must remember that equation (23) does not represent the experimental facts except when λT is large. Evidently we must find which one (or more) of the assumptions on which (23) is based is approximately true when λT is large and which is false when λT is small. One of these has already been pointed out, namely, that we have assumed that the standing waves in the box were independent of each other, in spite of a known interrelation, expressed in Fig. 2, between the amplitudes of the various frequencies in the original radiations. The second assumption has to do with the effect of the peep-hole. Although the loss of radiation through the hole may be made as small as we please, it can never be reduced to zero. Now equation (30) shows that if there were no loss through the peep-hole, the radiations of high frequency would contain nearly all of the energy, leaving very little for the molecules of the material particle in the box. This is surely not true in the case of actual experiment where the peep-hole is used. If, however, the rate at which energy of a given frequency escapes through the peep-hole is proportional to the rate at which energy is transferred to that frequency, the difficulty is overcome. It is, therefore, conceivable that, at least as far as this assumption is concerned, equation (22) could be altered to account for the losses through the peep-hole and in this way give an equation corresponding more nearly to the results of experiment.

Wien's Theory.—Let us assume a cylinder made of a perfectly reflecting material, permanently closed at one end, and provided at the other end with a perfectly reflecting movable piston. Let this cylinder be kept at a definite temperature, and let the

cylinder contain a tiny particle of some material substance at the same temperature. This material particle is placed in the cylinder for the same reason as in Rayleigh's box, namely, to insure that the radiation in the cylinder is the sort which could exist in equilibrium with a material body at the given temperature. The piston experiences an outward push due to the pressure of the radiation, so that work must be done on the piston if it is to be moved into the cylinder. Radiation striking this piston while it is being moved will show a Doppler effect, thus changing its frequency. Wien calculated this work and change of frequency for a whole reversible cycle, and arrived at an expression

$$E_\lambda = \frac{c^2 F(\lambda T)}{\lambda^5} \tag{32}$$

for the intensity E_λ for a given wave-length. Wien finds that

$$F(\lambda T) = \frac{h}{\varepsilon^{\frac{ch}{k\lambda T}}} \tag{33}$$

thus giving equation (24).

Planck's Theory.—Planck's equations are based on three groups of assumptions: (*a*) Dealing with the mechanism which produces radiation, (*b*) dealing with the thermodynamics of the radiation and its source, and (*c*) dealing with the manner in which energy of radiation depends upon the frequency.

(*a*) The light source is supposed to be made up of "oscillators" each of which contains positive and negative charges which are able to vibrate with respect to each other with some sort of harmonic motion. In terms of the picture of atomic structure, which we have already discussed, we might imagine an oscillator as being the positive nucleus, together with any one of the electrons in any one of the "shells." There must be such an oscillator for every frequency which the light source can give off. Now atoms of gases give line spectra, while molecules of gases tend to give band spectra. Solids and liquids tend to give continuous spectra. It would be consistent with our picture to assume that free atoms or free ions of a gas contain only a limited number of oscillators, each more or less independent of the other. Free molecules of a gas should have certain electrons existing under constraints which would not exist in free atoms or ions. These constraints should increase the number of possible frequencies of

the oscillators in a limited range, thus giving banded spectra. The constraints in a solid or a liquid should be still greater and more numerous, thus giving practically an infinite number of frequencies, and making possible the production of a continuous spectrum, *i.e.*, white light. Now let us assume again the thermodynamic box of Rayleigh. The material particle is emitting radiation and, at the same time, absorbing radiation. Equilibrium is attained when the energy received by the particle equals the energy emitted. Let L_ν be the average energy of one of the "oscillators" whose frequency is ν, and let E_ν be the intensity of radiation of this frequency in the thermodynamic box. Then Planck finds that

$$L_\nu = \frac{c^2}{\nu^2} E_\nu \tag{34}$$

(*b*) Boltzmann's equation for the entropy of a system is

$$S = k \log W + C \tag{35}$$

where k is $^2/_3\ \alpha$ as in the case of Rayleigh's formula, and where C is another "universal constant." The idea expressed by W is at first hard to grasp. It represents "the number of possible different states of the system which are necessarily indistinguishable by experiment." For instance, "suppose that there are in the enclosure, N oscillators of frequency ν, each having a mean energy L_ν, so that the total energy U is NL_ν. Suppose that we imagine the total energy split up into a large number P, of equal parts δ, so that $P = \frac{NL_\nu}{\delta}$. Then W is the number of ways P cards could be dealt to N players, the cards being supposed to be indistinguishable from each other, but the players distinguishable." The problem is much like the one which would confront a totally color-blind man who had a large number of samples of yarn, each of a different color, and who wished to find out in how many different ways he might arrange them so as to have a definite number of piles each containing the same number of samples of yarn. It can be shown that the number of ways in which the energy can be divided into P parts which are distributed among N oscillators is

$$W = \frac{(N+P-1)\,!}{(N-1)\,!\,(P)\,!} \tag{36}$$

Since N and P are necessarily large numbers, we may write this

(37)
$$W = \frac{(N+P)!}{(N)!\,(P)!} = \frac{\left(N+\frac{NL_\nu}{\delta}\right)!}{(N)!\left(\frac{NL_\nu}{\delta}\right)!}$$

Using Stirling's theorem

$$n! = \left(\frac{n}{e}\right)^n \sqrt{2\pi n}$$

we have

(38)
$$\begin{aligned} S &= k \log W + C \\ &= kN\left\{\left(1+\frac{L_\nu}{\delta}\right)\log\left(1+\frac{L_\nu}{\delta}\right) - \frac{L_\nu}{\delta}\log\frac{L_\nu}{\delta}\right\} + C. \end{aligned}$$

Now if S is the entropy of a system whose energy is U, then that system is in equilibrium at a temperature T such that

(39)
$$\frac{dS}{dU} = \frac{1}{T}.$$

Substituting (38) in (39), we have

(40)
$$\frac{1}{T} = \frac{dS}{d(NL_\nu)} = \frac{k}{\delta}\log\left(\frac{\delta}{L_\nu}+1\right)$$

$$\frac{\delta}{kT} = \log\left(\frac{\delta}{L_\nu}+1\right)$$

(41)
$$L_\nu = \frac{\delta}{e^{\frac{\delta}{kT}} - 1}$$

From (34)

(42)
$$E_\nu = \left(\frac{\nu}{c}\right)^2 \left(\frac{\delta}{e^{\frac{\delta}{kT}} - 1}\right).$$

(*c*) Now we have assumed, implicitly, in equation (34) that the *average* energy of all the oscillators varies continuously, *i.e.*, by increments which are infinitesimally small. In other words, equation (41) is founded on the basis of the Rayleigh formula, and as S approaches zero as a limit, (41) approaches as a limit, the Rayleigh equation (23). But Planck supposes that, although the *average* energy of a very large number of oscillators may be regarded as varying continuously, the energy of any individual oscillator varies by finite amounts (called "quanta") such that

(43)
$$\delta = h\nu$$

where h is a universal constant. In this way he arrives at a formula (equation (25)) which is identical with Wien's formula when λT is small and is identical with Rayleigh's formula when λT is large.

In the derivation of Planck's equation use was made of Boltzmann's entropy equation which is really a statement of the probability of the occurrence of some definite state. It is, therefore, to be expected that the physical basis of Planck's equation will be found in the *chance* that the oscillators will be in some definite condition. This has been well expressed by Campbell as follows:

"The physical basis of Planck's explanation of why the radiation of high frequency contains less energy than that which is allotted to it by the principle of equipartition, may be stated roughly thus: Radiation of a given frequency can receive energy only in finite increments δ; the magnitude of these increments is greater for the radiation of higher frequency. The chance that the system will be in a condition such that an amount of energy δ can be transferred suddenly and discontinuously from an oscillator to the radiation decreases very rapidly as δ increases. Consequently, although when a radiation of high frequency receives energy it receives more than a radiation of low frequency, the chance that it will receive any energy at all is so much less than in the case of a radiation which can take energy in smaller increments that the average energy of the latter radiation over a long time is greater than that of the former."

From what has been said, it is very evident that Planck's third assumption considers the discontinuities in the emission and absorption of radiation to be due to some peculiarity in the "oscillators" of the material substance and not to some peculiarity in the radiation itself or in the medium (æther) through which the radiation travels. A formula identical with (26) may be obtained by assuming that the discontinuities are inherent in the nature of radiation itself, for we could just as well have applied Boltzmann's equation (35) to the energy of the radiation U_ν instead of to the energy of the oscillators L_ν. Then instead of dividing the energy into P equal parts and distributing it among N oscillators, we should have distributed it among N wave trains. The final formula is identical with what we had before, but the point of view is quite different. It will be seen later that a more

consistent picture is obtained by limiting ourselves to the view that the discontinuities are due to the nature of the oscillator itself. The original derivation of Planck's equation, as given above, requires a complete rejection of the principle of the equipartition of energy, at least so far as individual electrons are concerned, and therefore denies the Hamiltonian principle of least action on which the idea of equipartition of energy is based. In other words, Planck's viewpoint abandons what was once considered the foundation of mechanics and sets up a new system of mechanics for electrons.

The usefulness of the quantum theory is by no means confined to the study of radiation from a "black body." It has been applied in one form or another to a study of atomic heats, chemical reactions, photo-electric effect, Stokes' law of fluorescence, the limiting frequencies of X-ray spectra, atomic structure, emission spectra of all sorts, the reflection, refraction and diffraction of light, and to the diffraction and scattering of X-rays.

Atomic Heats.—On the assumption that the law of equipartition of energy holds true for atoms each of which has three degrees of freedom, the average energy of each atom would be $3 \times {}^2/_3 \alpha T = 3kT$. If n is the number of atoms per gram-atom, then the energy of one gram-atom is $3nkT$. The energy per degree is the atomic heat,

$$C_v = 3nk. \tag{44}$$

Substituting the values of n and k we have Dulong and Petit's law that the atomic heat of a solid is 2.49×10^8 ergs, or 5.95 calories. Experimentally at room temperature most solids have atomic heats very close to this value, but there are several notable exceptions. If the measurements are made at reduced temperatures, the atomic heats of all substances fall considerably below 5.95 calories. If the temperature is sufficiently low, the atomic heats are nearly zero. If the measurements are made at high temperatures, it is found that the atomic heat of all substances approaches 5.95 calories as a limit.

Einstein assumed [30] that the whole heat energy of the solid is contained in the Planck oscillators. In the simplest case the natural frequency of all the oscillators might be assumed to be the same and each atom would have one oscillator. For any single

oscillator, vibrating in only one direction, the average energy is given by equations (41) and (43) as

$$L_\nu = \frac{h\nu}{\varepsilon^{\frac{h\nu}{kT}} - 1}. \tag{45}$$

Since the oscillators must be assumed to vibrate in all directions, we have for the energy of each oscillator

$$C_1 = \frac{d}{dT}\left(3L_\nu\right). \tag{46}$$

The heat capacity of a gram-atom of the substance is therefore

$$C_1 = n\frac{d}{dT}\left(3L_\nu\right) = 3n\,\frac{\varepsilon^{\frac{h\nu}{kT}}\left(\frac{h\nu}{k}\right)h\nu}{\left(\varepsilon^{\frac{h\nu}{kT}} - 1\right)^2 T^2}. \tag{47}$$

The true atomic heat, as calculated by Einstein, differs somewhat from this because the solid must have a great number of oscillators. Although these will have different natural frequencies, they must be less than some limiting frequency which is characteristic of the substance investigated. Such considerations make it possible to calculate the atomic heats of substances with considerable accuracy. A comparison of the simple formula (47) with (44) is sufficient, however, to show that the correction of Dulong and Petit's law is in the right direction.

$$\frac{C_1}{C_0} = \frac{\varepsilon^{\frac{h\nu}{kT}}\left(\frac{h\nu}{kT}\right)^2}{\left(\varepsilon^{\frac{h\nu}{kT}} - 1\right)^2}. \tag{48}$$

When $\frac{h\nu}{kT}$ is very small $\frac{C_1}{C}$ approaches unity, thus agreeing with the experimental fact that Dulong and Petit's law holds at high temperatures. When $\frac{h\nu}{kT}$ is large, $\frac{C_1}{C}$ approaches zero, thus again agreeing with experiment.

Campbell has pointed out that, "The theory of specific heat leads to the view that the heat energy of a body is distributed among oscillators, not of all possible frequencies, but of a comparatively small number of definite frequencies all of which are less than a certain limit. Unless we are to conclude that the

remarkable agreement between experiment and theory which was found is misleading, it is absolutely necessary to assume that the part of the complete radiation emitted by such bodies which has frequencies higher than this limit does not come from oscillators of the same natural frequency as the radiation. Now if each form of radiation does not come from an oscillator of the same frequency, the hypothesis which has been suggested as to the constitution of oscillators offers no explanation as to how the radiation comes to be emitted in finite amounts $h\nu$, and yet it is the assumption that the radiation is so emitted which is really fundamental in Planck's theory of radiation and leads to an agreement with experiment." This objection may be obviated by assuming that equation (48) only deals with the outmost shell of electrons in the atom.

Chemical Reactions.—The quantum theory has been applied with considerable success to the theory of chemical reactions by S. Dushman.[31] He starts with the two following considerations: "(1) From the known law of variation of reaction velocities with temperature, and from dimensional considerations, the velocity constant of a unimolecular reaction must satisfy a relation of the form:

(49) $$k_1 = \nu \varepsilon^{\frac{-Q}{RT}}.$$

Where k_1 is the velocity constant,
Q is the heat of reaction,
R is the gas constant,
T is the absolute temperature.

"(2) As Haber has shown, the quantum theory does apply with a fair degree of success to the calculation of heats of reactions. Furthermore, the quantum theory has been shown to be applicable to all processes in which energy absorption or emission is accompanied by the transfer of an electron, whether it be from one atom to another, or from one position to another position in the same atom. In all these cases the conclusion is forced on us that the energy transfer occurs in multiples of a unit quantum $h\nu$, where ν is the particular frequency of the energy radiated or absorbed.

"These two considerations lead to the conclusion that the constant of a unimolecular reaction has the general form,

(50) $$k_1 = \nu \varepsilon^{-\frac{h\nu_A}{kT}}$$

since $Q_A = Nh\nu_A$ [32] and therefore $\frac{Q_A}{RT} = \frac{Nh\nu_A}{RT} = \frac{h\nu_A}{kT}$. This would still leave ν undetermined.

"Now the frequency ν denoted the rate at which the active molecules dissociate. It seems reasonable to expect that in some manner this frequency ought to be related to the potential energy of the constituent atoms, that is, to the heat of activation. The writer has, therefore, assumed that

$$\nu = \nu_A = Q_A/Nh \tag{51}$$

and the rate of a unimolecular reaction is therefore given by the relation

$$-\frac{dC}{dt} = C\nu_A \varepsilon^{-\frac{h\nu_A}{kT}} \tag{52}$$

so that

$$k_1 = \nu_A \varepsilon^{-\frac{h\nu_A}{RT}} = \frac{Q_A}{Nh} \varepsilon^{-\frac{Q_A}{RT}} \tag{53}$$

where C is the concentration of reacting substances; Q_A is the heat of activation per mol of reactant, and N, h, R, and T have the usual significance.

"This equation we may consider as the fundamental relation for the rate of any unimolecular reaction that is dependent on the temperature.[33]

"By substituting in equation (53)

$$N = 6.062 \times 10^{23}$$

$$h = \frac{6.55 \times 10^{-27}}{4.184 \times 10^{7}} \text{ (cal. sec.)} \tag{54}$$

we obtain for the rate of any unimolecular reaction at a given temperature T, the expression

$$-\frac{dC}{Cdt} = 1.048 \times 10^{10} Q_A \varepsilon^{-Q_A/RT} \tag{55}$$

where Q_A is the heat of activation per mol, in gram-calories, and dC/dt denotes the relative change in concentration of the reacting substance per second."

Since

$$k_1 [A_2] = -\frac{d[A_2]}{dt} \tag{56}$$

it follows that

$$\log k_1 = 10.0203 + \log Q_A - \frac{Q_A}{4.571\,T} \quad (57)$$

"that is, from a single determination of the velocity constant at any given temperature it should be possible to calculate the heat of activation, or *vice versa*."

"As shown by Trautz, the heat of activation can also be calculated from the temperature coefficient of k_1, according to van't Hoff's equation. Combining this relation with that for Q, it is possible to check the above theory on actual experimental data in the case of the dissociation of phosgene (the only uncatalyzed unimolecular reaction whose velocity constant has been measured). The agreement is found to be very satisfactory."

Dushman has extended his theory to bimolecular reactions with the following results:

"As shown by Trautz and others, the velocity constant k_2, of a bimolecular reaction in gases, can be calculated from considerations based on the kinetic theory of gases. This theory is shown by the writer to be in accord with the experimental data in the case of several reactions.

"Since the equilibrium constant K of any reaction is given by the value of k_1/k_2, it follows from the above theory that, for any homogeneous gas reaction, it ought to be possible to calculate the free energy from data on the total energy of the reaction, or *vice versa*. In other words, this theory leads to a relation which is similar in certain respects to that derived by Nerst on the basis of his heat theorem.

"Working over the available data on homogeneous gas reactions, it is shown that the agreement between values of the heat reaction calculated from equilibrium constants by means of the above theory, are in fair accord, in a large percentage of the cases, with the total heats actually observed. The results also show that the relation suggested for unimolecular reaction velocities can be regarded, at present, as only approximately true.

"However, from the very fact that it yields such satisfactory agreement in a large number of cases, it must be of fundamental significance and probably represents an ideal relation which would hold true in all cases if it were not for the existence of other factors, at present unknown. The theory also brings out one more relation between the quantum theory and chemical reactions."

Bohr's Theory.—We have seen how the quantum theory with its constant h has been useful not only in helping us understand the light spectra of hot solids and liquids, but also in explaining such widely different phenomena as the variation of atomic heat with temperature and the velocity of chemical reactions. But these are not the greatest achievements of the quantum theory, for by it we are able to predict the spectra of at least the more simple elements not only in a general way, but even to the point of calculating the frequencies of the different lines in the spectra. In order to do this we must take up Bohr's theory of the nature of the Planck's "oscillators."

Bohr assumes that energy is radiated according to the laws of a Planck oscillator. His viewpoint is like Einstein's. It is just the opposite of Planck's. Planck thought of the amount of energy for a given frequency as being proportional to the frequency. Bohr thinks of the frequency as being proportional to the amount of energy available. It should be noted that in all the quantum theory, the interrelation between energy and frequency is thought of as being due to the mechanism of the radiator and the receiver (*i.e.*, of the oscillator), and is not supposed to be due in any way to the nature of the medium through which the radiation passes. Attention is so strongly focussed on the manner in which the radiation is produced and the way in which it is absorbed that the method of transmission of the radiation is hardly mentioned. But there is nothing inherent in the quantum theory which requires us to give up our "old-fashioned" idea of an æther which is capable of transmitting any sort of electromagnetic vibration we desire, from the wave front of large area given off by the modern radio broadcasting station to the wave front of more limited area sent out by the directive antenna of a commercial "radio central," or the wave front of exceedingly limited area described above in the treatment of the photo-electric effect.

Bohr's theory concerns itself only with giving us a picture (shall we say a "quantized" mechanical analogy?) of the source of radiation in the atom which shall be consistent with the known experimental facts of radiation and especially with the spectra which are known to be characteristic of the various kinds of atoms. Since the atom of hydrogen is the simplest possible atom, containing as it does only one electron, we will first give its

structure as pictured by Bohr. According to this picture, the electron in the hydrogen atom is constantly rotating about the positive nucleus. There are only certain possible orbits in which it can travel. These orbits are defined by the equation

$$\int p dq = nh \tag{58}$$

where h is Planck's constant ($= 6.55 \times 10^{-27}$ ergs sec.), and n is any integer, and where p and q are the generalized momentum and generalized coördinate for the orbit under consideration. In case the orbit happens to be circular, p is the moment of momentum and q is the angle turned through and equation (58) becomes

$$\int_0^{2\pi} mv\alpha dq = nh \tag{59}$$

where m is the mass of the electron, v is its linear velocity and α is the distance from the electron to the positive nucleus.

Equation (58) means that, in order to rotate in a given orbit, the electron must possess a definite amount of energy which is a characteristic of that particular orbit.

In order to compel the electron to leave one orbit for another which is further from the positive nucleus (*i.e.*, for which n is larger), it must be given an amount of energy from some external source equal to the difference in the characteristic energies of the two orbits. If it is allowed to drop back to an orbit which is closer to the nucleus (*i.e.*, for which n is smaller), it must give up in the form of radiation an amount of energy which is equal to the difference in the characteristic energies of the two orbits. While rotating in a steady state in a given orbit, the electron does not radiate energy at all. This gives rise to Bohr's second equation.

$$U_k - U_j = h\nu \tag{60}$$

where U_j and U_k are the energies of the electron when rotating in a steady state in two orbits whose n of equation (58) is respectively j and k.

Now the energy of an electron in a given orbit is partly potential and partly kinetic. The potential energy is

$$V = -\frac{Ze^2}{\alpha} \tag{61}$$

where Z is the atomic number so that Ze is the charge on the positive nucleus. The kinetic energy is

$$T = \frac{1}{2} mv^2 = \frac{1}{2} m\alpha^2\omega^2 \tag{62}$$

where ω is the angular velocity. We may eliminate ω^2 by remembering that if the electron is rotating in a steady (*i.e.*, non-radiating) state about the nucleus, and if the nucleus is assumed to have infinite mass in comparison to that of the electron, then the centrifugal force must equal the centripetal force, so that

$$\frac{mv^2}{\alpha} = m\omega^2\alpha = \frac{(Ze)e}{\alpha^2}. \tag{63}$$

Equation (62), therefore, becomes

$$T = \frac{Ze^2}{2\alpha} \tag{64}$$

so that

$$U_j = V_j + T_j = -\frac{Ze^2}{2\alpha_j} \tag{65}$$

$$U_k = V_k + T_k = -\frac{Ze^2}{2\alpha_k}$$

The radius α of the orbit can hardly be measured directly. We must express it in terms of quantities which are already known. This may be done as follows:

From equation (59),

$$2\pi m\alpha^2\omega = nh$$

so that

$$\omega = \frac{nh}{2\pi m\alpha^2}.$$

If this is substituted in (63), we get

$$\alpha = \frac{n^2h^2}{4\pi^2 mZe^2}. \tag{66}$$

Equations (65), therefore, become

$$U_j = -\frac{2\pi^2 Z^2 e^4 m}{n_j^2 h^2} \tag{67}$$

$$U_k = -\frac{2\pi^2 Z^2 e^4 m}{n_k^2 h^2}.$$

Equation (60) which gives the frequency of radiation to be expected when an electron falls from orbit n_k to orbit n_j becomes

$$h\nu = \frac{2\pi^2 me^4 Z^2}{h^2}\left(\frac{1}{n_j^2} - \frac{1}{n_k^2}\right) \tag{68}$$

$$\nu = \frac{2\pi^2 me^4 Z^2}{h^3}\left(\frac{1}{n_j^2} - \frac{1}{n_k^2}\right) \tag{69}$$

$$= N_\infty Z^2\left(\frac{1}{n_j^2} - \frac{1}{n_k^2}\right).$$

Equation (69) is identical with the simplest empirical formula for the spectral lines of atomic hydrogen. The calculated value of N from (69) is 3.29×10^{15}. The value which makes the empirical formula fit the experimental facts is 3.2903×10^{15}.

Now the derivation of (69) was based on a definite picture of the structure of the hydrogen atom in which the ordinary laws of electrostatics are supposed to hold between the electron and its nucleus, but in which radiation occurs in accordance with a quantum law instead of ordinary electromagnetic theory. It can hardly be assumed, however, that equation (69) could not be derived upon some other hypothesis. All our pictures of atomic and electronic phenomena are necessarily figures of speech, or analogies. Our equations also are really analogies expressed in mathematical form. Often the same mathematical statement can be interpreted in terms of two widely different mechanical pictures. The same equations which give the effect of inductance and capacity in an electric circuit also give the effect of inertia and a system of springs in a mechanical model. Fourier's formulas for the conduction of heat through a solid are used to this day, but the theory of heat used in their original derivation is quite untenable. It is indeed true that no one has yet offered a derivation of equation (69) in competition to Bohr's, but this does not mean that it cannot be done.

One interesting start has already been made in this direction by Langmuir.[38] It will be remembered that the "static atom," with the aid of Thomson's law of force (equation (1)), was in excellent quantitative agreement with experimental data covering such widely separated physical properties as ionizing potentials, photoelectric effect and compressibilities. Now Thomson's law contained one arbitrary constant. It follows directly from equation (1) that when the electron is in a position of equilibrium, this constant is equal to the distance r from the electron to the positive nucleus. In terms of Bohr's picture, this distance would be the radius of

the orbit of the electron. Using the symbols which we have used in dealing with Bohr orbits, rather than those of equation (1), we have from (66)

$$C = \alpha = \frac{n^2h^2}{4\pi^2 mZe^2} = \frac{\frac{1}{m}\left(\frac{nh}{2\pi}\right)^2}{Ze^2}. \tag{70}$$

Equation (1) then becomes

$$F = \frac{Ze^2}{\alpha^2} - \frac{\frac{1}{m}\left(\frac{nh}{2\pi}\right)^2}{\alpha^3}. \tag{71}$$

This equation has two peculiarities. First, it shows that if Thomson's equation is to be used to correlate the static atom with the experimental data on spectra, then his "constant" c, of equation (1) is not really a constant at all, but is instead any one of a series of constants of the form $\frac{n^2C}{Z}$ where n is any integer, Z is the atomic number and $C = \frac{h^2}{4\pi^2me^2}$. Second, it puts the quantum number, h, only in the inverse cube term. This would seem to indicate that Coulomb's inverse square law actually holds rigorously for the attraction between the nucleus and the electron, but that there is some other repulsive force (Langmuir calls it a "quantum force") represented by the inverse cube term, which is superimposed upon it. This repulsive force would not be expected to apply to an electron which did not belong to some definite atom, *i.e.*, for an electron for which $n = 0$. This is consistent with the fact that Rutherford's calculations, using Coulomb's law alone, on the path of alpha particles passing near an atomic nucleus agree well with the results of experiment.

Using equations (70) and (71) we may calculate at once the energy of the system for any value of n.

$$\begin{aligned} -U_j &= \frac{Ze^2}{\alpha} - \frac{\frac{1}{m}\left(\frac{n_j h}{2\pi}\right)^2}{2\alpha^2} \\ &= \frac{4\pi^2Z^2me^4}{n_j^2h^2} - \frac{2\pi^2Z^2me^4}{n_j^2h^2} \\ &= \frac{2\pi^2Z^2me^4}{n_j^2h^2} \end{aligned} \tag{72}$$

The first term of equation (72) is identical with the Bohr expression (61) for the potential energy of the electron. The second term is identical with the Bohr expression (64) for the kinetic energy. This was to have been expected, for in the

original force equations, the inverse cube term of equation (1) and the centrifugal force of equation (63) were each introduced for the same purpose, namely, to bring the electron to equilibrium with respect to the Coulomb attraction force.

In terms of the picture of the static atom, the loss in energy due to an electron falling from an equilibrium position n_k to another equilibrium position n_j is

$$U_k - U_j = h\nu = \frac{2\pi^2 me^4 Z^2}{h^3}\left(\frac{1}{n_j^2} - \frac{1}{n_k^2}\right)$$

$$\nu = \frac{2\pi^2 me^4 Z^2}{h^3}\left(\frac{1}{n_j^2} - \frac{1}{n_k^2}\right) \tag{73}$$

which is identical with equation (69).

This means that, if we are willing to arbitrarily assume equation (70), or if, some day we can find a rational derivation for equation (70) apart from Bohr's theory, the static atom with the aid of Thomson's law of force is capable of explaining the spectra of atoms with identically the same success as the Bohr atom. Really, the difference between the two atomic pictures is largely a matter of words. The static-atom picture considers the electrons of a non-radiating atom to be either stationary (except for some sort of heat motion) or else moving about in such a way that the position assigned by the picture represents the *mean* position. In order that such an atom may radiate, the electron merely drops from one such equilibrium position to another closer to the nucleus, radiates its excess energy and comes to rest at (or about) the new equilibrium position. The Bohr picture considers the electrons to be in a state of motion about the nucleus without producing radiation. When the electron drops to a new orbit of smaller radius, it radiates its excess energy and then rotates without further radiation. As G. N. Lewis says[39] "that state of motion which produces no physical effect whatsoever may better be called a state of rest." We shall see later that Bohr orbits may best be considered as ellipses rather than circles. If the nucleus is one focus of an ellipse, the position given by the static-atom picture may well be the other focus. So we see that, after all, the two pictures of atomic structure, which at first seemed so widely different, are really pretty much the same but are expressed in different words and employ a slightly different viewpoint.

(To be concluded.)

THE INTERRELATIONS OF MODERN PHYSICS AND MODERN PSYCHOLOGY.*

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I. THE NATURE OF EXPERIENCE.

THE modern sciences are ordinarily contrasted with those of more ancient times as being based upon experience rather than upon pure reason or the guess work of mere speculation. This is true both of the modern physical and the modern psychological sciences. Both supposedly rest upon a sound empirical bed-rock, although the followers of physics are inclined to accuse psychologists of speculation and guess work, and the converse criticism is not infrequently made. While we may be quite clear that our science must be rooted in experience and may be satisfied that it is so, yet we may be quite lacking in a clear conception of the nature of experience and just how our scientific knowledge grows out of it.

Our first task will be to consider briefly the meaning of the term "experience." We shall then deal with the manner in which modern physical ideas are apparently derived from experience, after which we shall treat of the corresponding relationship of modern psychological notions to their empirical basis. This will be followed by a discussion of the relations between these two sets of conceptions, the physical and psychological, which follow from our analysis. Our final problem will be to inquire how the results of physics and of psychology can be combined to yield a more comprehensive interpretation of the universe in its entirety.

The present is a time of stupendous triumphs for our methods of physical investigation. It is also, particularly in America, a period of intense controversy concerning the methods and problems of psychology. We can study the processes of physical science as they are presented in the multitudinous labors now before us and we should be able to arrive at secure conclusions concerning their nature. In the domain of psychology, however,

* Read by Dr. Elton Mayo, Wharton School, University of Pennsylvania, at a meeting held Thursday, January 24, 1924.

our conclusions may be wanting in firmness of foundation, since the methods of different psychologists differ so markedly from one another. Although I shall consider various conceptions of psychology, I shall advocate only one of these, and my own final results will thus depend to a certain degree upon personal preferences regarding the division of scientific labor. However, I hope to show that the system which is to be outlined promises to be the most fruitful one.

If we ask the question, "What is meant by the term experience?", we shall be tempted to seek the answer by a psychological rather than by a physical inquiry. However, this question is in reality prior to all empirical scientific investigations, whether the latter purport to deal with matter or with mind. The commonest notion of what is meant by "experience" is undoubtedly that it consists in a relation between an oberver and something which is observed, or, in philosophical terminology, between a *subject* and an *object*. This relation involves a *process* in which the object acts upon the subject. The subject is a conscious being, a psychical individual or a mind, the object may be a body, a force, a form of energy, or some agency outside of the organism, or, on the other hand, it may consist in some modification or condition of the observing organism itself. Although the idea of experience certainly implies ordinarily the presence of an object, nevertheless it is the *effect* of the object upon the subject which is emphasized. When one says "I had an interesting experience to-day," it is the subjective rather than the objective side of the situation which is stressed. The heart of experience as a conception therefore lies in the influences exerted upon the observer or conscious individual.

However, we can scarcely arrive at an adequate definition of experience in these terms without having a precise idea of what is meant by such words as "subject" or "observer." The most primitive explanation of the subject or psychical individual lies in the doctrine of the soul. According to this hypothesis the sentient individual is a *spirit*, that is, literally interpreted, a body formed of air or breath. Such an "anima" is readily conceived to be both active and sensitive, being capable of influencing and being influenced by the external world. It is clearly distinguished from the solid and more material living body. Although this idea of the soul predominated in primitive philo-

sophical thinking during a long period of time, it has practically been abandoned by modern critical thinkers. This statement holds not only for the crude conception of the soul as a body of vapor, but also for the more abstract refinements of the idea. However, some philosophers, and a very few psychologists, still refer to the soul as a sort of unknown X with no thinkable characteristics except the abstract capacity to do the various things attributed to it.

In retreating from the crudely primitive conception of the soul, philosophers have modified it and have offered substitutes for it along various lines. The "transcendental ego" to which we have just adverted—the unknown X which experiences and wills, without itself being experienced—is virtually a confession that the subject must be explained by experience, not experience by the subject. Materialistically inclined thinkers have substituted the body or living organism for the soul and have said that the former is in reality the active or sensitive agent. It is quite evident that the world outside of the organism acts upon it and is acted upon by it in turn. The difficulty here is apparently that the living body itself is known only through experience and cannot therefore legitimately be employed to define the latter. The upshot of centuries of controversy concerning this problem appears to be that experience itself is a more fundamental notion than that of either subject or object and that we must accept it frankly as an ultimate datum.

How, then, shall we conceive experience without necessary reference to a subject or observer, and possibly also without reference to something which is observed? Modern psychologists and philosophers have arrived at such a conception. It is a conception which treats of the most common-sense of all realities, yet one which it is extremely difficult to impart to any common-sense individual. Common-sense deals directly with experience, and yet does not recognize its existence, probably because common-sense has nothing with which to contrast experience.

In order to realize this conception of experience as a thing in and for itself, let us imagine ourselves in the position of a primitive man who has the capacity to think and yet who has never utilized this capacity. In this state we should be devoid of all theories concerning the nature of the world and the self. We should not, however, be unconscious; the landscape, the

figures of other men, etc., would be spread visually before us; we should hear and feel and taste and smell. Yet we should not know *why* we saw, why we heard, why we felt, or why we tasted, or smelled. Neither should we know *who* was doing these things. There is also a sense in which we should not be able to say *what* we saw, what we heard, what we felt, what we tasted, or what we smelled. We should be having a great multiplicity of *experiences*, but these would stand all by themselves without being explained or suggesting anything further.

Suppose now that we began for the first time to think. Naturally our thought would refer to our experiences and our thought itself would be just one other new kind of experience added to the others, and it could in turn itself be "thought about." Thoughts are experiences which have become symbols of other experiences, the latter being the meanings of the thoughts. There is thus between thought and its signification a relationship similar to that which is supposed to exist between subject and object and from which, as a matter of fact, the latter relationship is derived. The real self, or ego, in other words, is the thought process itself.

The first stages of thinking must have been concerned with the creation of a set of symbols by means of which the varieties of experience could be individually designated. The result was a form of language descriptive of pure experience. Experience in general as the subject-matter of thought was not, of course, restricted to the examples which we have given above and which correspond to the so-called five senses, since there are other facts in experience besides those of vision, audition, touch, taste and smell. To these latter must be added internal feelings of pain, comfort, posture, and the like, as well as faint images or blurred reproductions of factors in all departments of experience. Still the first step taken by thought must be to catalogue the facts which are before it, rather than to speculate concerning their origin or other relationships.

When we look upon science as a form of knowledge we must realize that it is essentially a system of thought. Experience which aroused and contained no thought could not be scientific. Only by thinking does science develop and only as thought does it really persist. But there are many different kinds of thought, of which science is only one and a very special kind. Nevertheless,

in all thought there inevitably reside factors which are fundamental to scientific method. Common-sense is a mode of thinking, and science grows out of common-sense. The foundation of scientific, as of any other form of thinking, lies in the establishment of permanent relations between words and their meanings in experience.

Experience, as we have just tried to define it, is the sum total of what philosophers sometimes call the *Given*. From this expression it may be inferred that not everything is given and that we might also refer to the *Taken*. Thought does not long confine itself to direct experience; some things are *presented* while others are assumed or represented. Thought, either as common-sense or as science, thus pursues a course of give and take, or rather receive and take. What is "taken" in this sense lies beyond experience. One way of stating the problem of the present lecture is to say that our task is that of separating what is given from what is taken. We shall argue that this distinction corresponds, at least approximately, with that between the psychological and the physical methods, respectively. To separate the given from the taken is not necessarily easy, since much of the latter is "taken for granted" (or taken for given), although not legitimately.

I stated at the outset that our first effort would be to determine the nature of experience. Thus far, if I have been successful at all, it would seem that we have merely located or identified experience without having given a description of its nature. It is questionable, however, whether such a thing as experience can be defined in words. We can merely employ words to point it out or to designate it. Thought finds experience and names it and then may utilize the name to return to it again. Thus the only way in which we can reveal the nature of experience by words is to employ words to lead our thoughts back to empirical reality and away from the unrealities with which thought frequently disguises it.

Using words for this purpose, we may say that experience is a complex and changeable combination of qualitative elements. Visual experience consists of colors and visual depth (including under colors, variations of light and shade). Auditory experience comprises musical tones and noises in various combinations. Tactual experience may be said to embrace feelings of touch, warmth and coolness, and cutaneous pain. Gustatory, or taste,

experience is constituted of various combinations of bitter, sweet, salt and sour, while olfactory, or smell, experience contains a wealth of qualities well nigh inexhaustible. In addition we must mention the bodily, or seemingly internal, experiences, such as kinæsthesis (corresponding to bodily movements), organic pain, nausea, well-being, the experiences accompanying excretory and reproductive functions, etc. These are the components ordinarily called "sensations" by psychologists, their combinations making up various "perceptions" or consciousness as a whole.

If we think of experience along these lines we shall not be tempted to say that it is experience *of* anything or *by* anything. In the absence of attempts to explain experience, such things as colors or musical tones are neither "of" nor "by"; they are sufficient unto themselves and also sufficient unto many other ideas which come later and by which we attempt to explain them. In saying this we are not attempting to deny that experiences actually do have causes lying outside of themselves, but these causes are in the first instance unknown and hence not necessarily conceived. Moreover, we are not denying that experiences are individualized in such a way that "my experience" can properly be distinguished from "your experience," but this does not imply the existence of any mysterious "subject" or subjects; it merely admits that there are many different experiences, not all of which are combined into a single system.

II. THE RELATION OF MODERN PHYSICS TO EXPERIENCE.

Thought does not long rest content with a mere recounting of the facts of experience, it soon reaches out from the Given and begins to "take." It is looking for an explanation of the varieties and the uniformities in experience. Such a process demands that thoughts should refer to meanings which lie beyond the presented facts. It is my thesis that modern physics, although it starts with experience, has reached far beyond it and expresses its final results in terms quite different from those of the Given. In this respect it resembles metaphysics, which also seeks essentially a reality lying beyond experience or "mere appearance." Modern physics apparently differs from metaphysics, however, in that the latter has not as a rule even started with experience but has rather taken its departure from so-called logical and actually arbitrary premises.

Let us consider the exact manner in which physical thinking is related to experience as we have defined the latter term.

The physical way of thinking is undoubtedly more primitive than one which confines itself strictly to what is positively given. It is a common philosophical observation that thought tends to deal primarily with things lying beyond itself; the mind has a powerful objectifying tendency and only with great difficulty turns in psychology to consider its own nature. Nevertheless, as psychologists and philosophers, we find it very difficult when looking backward to understand exactly what this objectifying tendency is and how it could have arisen. How is it conceivable that our thought should ever depart from what is immediately presented to it as experience? Whence comes this urge to believe in the existence of things which are not immediately before us?

One source of the tendency is probably to be found in the difference between perception and memory, or, together with the latter, imagination. Clear perceptions of definite things forming parts of immediate experience are ordinarily fleeting in character but their memory images remain and can be called up at any time. These images resemble the perceptions in general form but are very deficient in vividness or intensity when compared with the experiences from which they arose. It is thus impossible to identify them with the perceptions in question, although they constantly represent the latter in our consciousness. Accordingly, the images become symbols of absent realities, and since the latter are not in experience they must exist elsewhere beyond experience.

The most primitive way of thinking about things which were not included directly in the Given was therefore that of considering things as perceived to have a continued existence when not perceived. A man's home, the ocean, or the sun, while frequently present as actual parts of experience, were at other times absent; yet they were still remembered or imagined, and thus thought about, and were conceived to have a continued existence similar to that which they enjoyed in consciousness. They, and many other similar things, were conceived as coming into or as going out of experience without suffering any essential changes, always leaving behind them the residual memory impressions which united with them again upon their return. As language developed, all such recurrent and remembered experiences received definite and distinctive names, which further contributed to a belief in their

permanency. The part played by language in the development of scientific and especially of physical thinking, is of the utmost importance. Science, as a completed system, is essentially a system of words or symbols, and although these words have value only by referring to meanings, the meanings could not be combined into a science without the words.

The primitive physical thinker thus began by "projecting" certain parts of his experience into a supposed objective world. This objective world in turn contributed factors of all kinds to his experience. Indeed, the Given was given by the world. By observing and reflecting upon those sections of the world which thus supposedly came into his experience the primitive physicist hoped to arrive at a description of the permanent universe. Such a description constituted his scientific teachings.

However, even the crudest of physical thinkers recognizes that not all of his experience is contributed directly and without modification by a world outside. Images and thoughts in the form of words are at least vaguely distinguished from the vivid things to which they refer. Internal bodily feelings, such as those of well-being, fatigue, nausea, etc., are placed in a different category from the presentations of sight, hearing and touch. These "internal" experiences, which seem to lie inside of instead of outside of the skin, stand for the "self" as opposed to the world. However, between the self and the world many intimate relationships exist. A person's body as it is seen and touched by the person himself is a reality of the external world, but its positions and motions are followed very closely by certain groups of internal feelings. Changes in the condition of the body, for example mechanical injuries, are accompanied by specific internal experiences. Moreover, a man's own body is a peculiar object in the world in that, by executing proper movements, it obeys the inner flow of ideas and wishes. The fact that all other objects in the world fail to exhibit this immediate obedience tends to enhance further the contrast between the self and the world; the man's own organism, even as externally perceived, being included as part of the former.

The effort of the primitive physicist to achieve an account of the world, by describing portions of it which from time to time appear within his experience, soon encounters difficulties. Evidence accumulates to prove that experience cannot be divided

sharply into portions which are objective and others which are subjective. Primordial thinkers may even have regarded such experiences as pain and nausea as being temporary visitations of an external agency, but these phenomena were early rejected from the domain of physical investigation. The experiences associated with the so-called five senses, however, were at first accepted naïvely as presenting directly the nature of objective reality. It is true that many of the Greek philosophers asserted the subjective and totally illusory character of all sensory experience, but there was a great gap between the thinking of these men and that of common-sense, from which modern physics descended. "Seeing is believing," yet at the very dawn of modern science we find physicists explicitly doubting the objective significance of certain visual experiences. Kepler, as well as Newton, definitely asserted that color is an impression produced upon the brain and is a property absent in physical objects by themselves. Although this view was far from being universally accepted among scientists, even in Newton's day, it has now become a classical scientific tenet. Color, including variations of light and shade, has been relegated definitely to psychology.

When visual objects are stripped of color (including their brightness value), they have actually been robbed of all concrete existence. However, we may still conceive them as possessing, or rather consisting in, definite three-dimensional forms and sizes. Furthermore, we can have recourse to other domains of experience, such as the tactual, which endow the same objects with "tangibility" or mass. The smell, the taste, and the sound of the body may also still be regarded as objective characteristics. These latter features did not as a matter of fact persist long as supposed real properties of physical bodies. Indeed, we find modern physics at an early stage of development restricting its world to a very few empirical characteristics, remarkably few when we consider the manifold variety which is presented directly by experience itself.

I am referring now to the so-called C.G.S. system of physical units, according to which all physical conceptions are to be reduced exclusively to terms of the gram, the centimetre, and the second. These units of space, mass and time represent the scientific equivalent of the so-called "primary qualities" of matter as defined by the philosophers. These are distinguished

from the "secondary qualities," which both the philosopher and the physicist regard as subjective, *i.e.*, as part of experience but not as part of a permanent world beyond or independent of experience. The notions of space, mass and time are certainly derived from experience and are exemplified in some form therein. Yet even before the appearance of the principle of relativity, which is essentially a critique of the C.G.S. system, physicists began to recast these concepts in abstract and logical form. Mass, for example, instead of being identified with the tactual experiences with which we are so commonly acquainted, was reduced to inertia or the degree to which a body resists modification of its mode of motion. Moreover, the space and time measures of the physicist did not uniformly coincide with those of direct experience, which were very frequently found to be "erroneous." Two distances which "seem" equally great are not necessarily so for physicists, and the same can be said of two apparently equivalent durations. Numerous philosophers, such as Bishop Berkeley, were very early in their claims that the primary qualities are just as subjective as are the secondary ones, but few physicists paid any attention to such idealistic speculations.

However, in the later nineteenth and early twentieth centuries the theoretical structure of physics was subjected to a succession of epoch-making changes, the full philosophical significance of which is still unappreciated. The first of these was involved in the discovery of radio-activity and the electron, which ultimately led to the replacement of the earlier notion of matter by that of *electricity* as the fundamental substance of the physical world. A second change came with Einstein's principle of relativity, which radically modified our notions of physical space and time. These two basic innovations, while they have greatly increased the scope of physical explanations, have carried them further away than ever from our immediate experiences.

Let us consider, first, the empirical status of the modern electrical theory of matter. When the objects of the physical world were conceived as aggregates of solid massive atoms the scheme was still capable of being represented by some form of imagery in consciousness. But when the solid atoms were replaced by the tiny electrical charges known as the electron and the proton (the ultimate negative and positive units, respectively), this possibility practically vanished. How shall we picture, or otherwise

imagine, an electrical charge? What is the difference, in terms of experience, between negative and positive electricity? Physics tells us of the differences in their behavior and relationships to one another, but has nothing to say of their inherent nature. When the modern physicist tells us that the material world is simply a configuration of small electrical charges, he is not only talking about something quite different from the world of experience, but about a world which we cannot even create artificially within experience. Mass has disappeared as a fundamental characteristic, and must needs be explained in terms of the essentially inexplicable electrical forces of the proton and the electron.

Just as the empirical notion of mass departed with the advent of the electrical theory of matter, so empirical space and time were quite ousted by the principle of relativity. In the face of the electrical theory it was still possible to maintain that the form or shape of the physical world could be depicted in experience, even if its substance eluded us. Einstein made it certain, however, that the sizes and shapes of physical objects cannot be considered as absolutely fixed, but must be regarded as relative to the conditions under which they are determined. Similar considerations apply to processes or to series of events in time, which according to the Einstein system must possess characteristics which cannot be imagined empirically.

To persons who are satisfied with merely verbal representations, it may seem that the explanations which are given by modern physics are quite adequate. And so, indeed, they are, when properly interpreted. But let any such person actually attempt to represent the fundamental hypotheses and equations of modern physics in other than verbal form, and he will see how impossible is the undertaking. If we picture an electron system visually, we are using the wrong materials and erroneous spatial relationships. We inevitably delineate the system in light, shade and color, instead of in electricity, while our space has a perspective rather than an Einsteinian form. *I believe, therefore, that we are forced to conclude that physics now describes the world in terms which are essentially unimaginable.*

If this is the case, how can we continue to regard physics as an empirical science, or even as a science at all? The answer is that, whatever its final form may be, the physical scheme can be

carried back to experience along the path which brought it into being. The theories of modern physics may be figments of pure reason, but these figments are definitely substituted for facts of experience, and hence can be replaced once more by the latter. Thus the images of stars, and their relationships, as seen by the astronomer, are the indubitable items of experience for which, in certain connections, the Einstein equations are a substitute. From the equations, definite empirical expectations arise regarding the relationships of the star images, and only when these expectations are verified is the theory regarded as true. In a similar way, the formulæ which represent the hydrogen atoms as particular combinations of protons and electrons lead us to expect definite lines or colors in the spectrum of hydrogen. We cannot identify this spectrum with the hydrogen atoms, but we have associated the two so that one has a definite implication for the other. The situation here is like that of the shape of the earth. It is impossible for us to imagine the earth in its true size, but if it is round we can have the experience of returning to our starting-point by sailing straight ahead, while if it is flat this experience will not be realized.

This view of physical theory as a logical and artificial scheme, which is justified only by its utility in enabling us to predict certain details of experience, is sometimes called *conceptualism*. The conceptualist in this sense would not regard modern physics as an attempt to *describe a universe* either within experience or beyond it. He would rather say that the physical scheme is a condensed formulation of certain special uniformities of experience which finds its significance only when traced directly back to these same empirical details. According to this view physics does not tell us anything new about experience or about reality outside of experience, but merely provides us with a convenient kind of bookkeeping for all of the facts which we already know. Even when theoretical analysis reveals the presence of unsuspected uniformities, this is of importance only because it simplifies the bookkeeping.

Sophisticated as the conceptualist's doctrine may sound, it is displeasing to those who have looked to physics to provide them with an understandable representation of the universe in which they live. Physics set out, we believed, to discover a world which is greater than the experience of any particular individual or any

given instant. Modern physical theory seems to present us with an account of such a world, but it is an account which is couched in terms which we cannot understand. Is there any alternative to the conceptualist's theory? Can we reinterpret the fundamental concepts of the physical system, so that they will be given direct empirical meanings, without tracing them backwards through the maze of logic and experimental technic out of which they came?

I believe that the answer to this question is affirmative, and I shall later attempt to disclose the manner in which the reinterpretation must be made. For the present I wish to summarize our conclusions concerning the relations of modern physical theory to experience. The physical thinker is not interested in experience in itself or for its own sake. He uses experience as a necessary instrument in seeking the nature of the permanent and law-abiding world upon which experience largely depends. At first he believes that this world is actually present or faithfully represented by certain parts of his experience, but as his thought progresses, it becomes divested more and more of empirical character. Eventually the modern physicist arrives at a logical system—an arrangement of symbols—which refers to a universe wholly outside of experience, and having a nature foreign to all empirical data. Nevertheless, the structure of this logical system has been moulded throughout by empirical influences. Physical theory is like a statue carved by a sculptor, different in material and form from its maker, yet a product of his activity.

III. THE RELATION OF MODERN PSYCHOLOGY TO EXPERIENCE.

Regarding the status of modern psychology in relation to experience many divergent opinions exist. Indeed, there are *numerous* modern psychologies, having as many different standings in this respect. I shall only attempt to state and to analyze the relations of psychology as I have conceived the science in my own thinking. I believe that my notion of psychology has been influenced by a contact with physical science somewhat more intimate than that of the majority of my confrères in the psychological domain.

Psychology began as the science of the soul. The primitive psychologist probably had no more interest in experience, in and for itself, than had the primitive physicist. He studied certain

types of experience which he thought might reveal to him the nature of the soul. Very soon, however, he found himself in a difficulty similar to that which faces the modern physicist. He discovered that he had conceived the soul as an indefinable "that which" has experience; he remained unable to specify the nature of the soul in empirically intelligible terms. In our preliminary discussion we have seen how the notion of the soul eventually disappeared from psychological arguments concerning the foundations of experience. This was a natural consequence of the vacuity of the conception.

The special experiences which interested students of the soul were as a rule distinct from those which attracted the attention of physicists. The latter were concerned mainly with visual and tactual impressions, whereas the early psychologists dealt with the more internal consciousness involved in feeling, volition, memory, etc. Each of these types of inner experience was explained by a special property, or "faculty" of the soul. When psychologists relinquished the soul the experiences in question still remained and invited study on their own behalf. In the beginning the physicist adopted certain other portions of experience as his particular materials, but as he progressed he dropped these, one by one, and the psychologist picked them up. Thus eventually the psychologist received the suggestion that he should study a variety of aspects of experience for their own sake, without reference to their supposed causes or explanations.

If we adopt this suggestion, we may define psychology as the science of all experience except the physical. Psychology is concerned with the properties of experience *per se,* without reference to its significance. Then if we agree that at the present moment physics has defined its own world in wholly non-empirical terms, there is no reason why we should not declare psychology the science of all kinds of experience whatsoever. Physics and psychology would thus be distinguished in that the former seeks through experience to learn the nature of a world outside, while the latter confines itself to experience alone. In accordance with this view psychology is the empirical science *par excellence,* and such I believe it to be.

However, it is only fair that I should admit again that not all psychologists would agree with me in the above definition. For example, there are those who hold that psychology is no more

a faithful account of actual experience than is physics, both sciences being equally artificial treatments, different in results because different in purpose. Thus, Titchener states that physics deals with experience regarded as independent of the individual, while psychology treats it as dependent (upon the organism). According to this view the study of experience without presupposition or special purpose is either impossible or is not a science; or possibly it should be considered a new inquiry, to be called *phenomenology*.

Other psychologists would say that, although it is the function of mental science to study certain kinds of experience for their own sake, this study does not necessarily extend to all portions of experience, even if they are neglected by physics. Psychology is concerned, according to this view, with the so-called inner experiences and in general with non-spatial forms. Relations between the inner and the outer factors may also be considered, but the latter make up the *contents* as opposed to the *acts* of awareness, which are of primary interest to psychology. Another alternative view is that psychology deals with the interrelations of experience and processes occurring in the individual organism, especially in the nervous system. This practically identifies psychology with what is known otherwise as psychophysiology.

In recent times there has arisen a movement known as *behaviorism*, which proposes to redefine psychology as an "objective" science, having the same general point of view and methods as physics. It is characterized only by its special subject-matter, the behavior of living organisms. According to behavioristic teachings, psychology can and must dispense with all such ideas as "consciousness," "sensation," "thought," etc., and instead of trying to elucidate these mysteries will be content to study the manner in which men and animals respond to stimuli. It is far from being my wish to deny that the problem of "behaviorism," thus stated, is a *possible* one. Still, I cannot admit such a definition of psychology, because it flies in the face of history and because it ostracizes from the domain of science problems which are of the utmost human importance. The behaviorist vaunts the empirical character of his methods and yet implicitly denies the possibility of a science of experience.

If we accept the behavioristic interpretation of psychology, we shall eventually be forced to class psychology as a subdivision

of physical science. The realm of physical investigation includes biology as the objective science of living beings. Organic behavior is merely a special aspect of physiology, or the dynamics of living matter. Ultimately, we hope to account for all physiological phenomena in terms of the electron and the proton, organisms differing from inorganic bodies only in complexity. It is apparent from their writings that behavioristic psychologists do not recognize these distinctions and relationships, but this fact has very little to do with the logical requirements to which their views must actually be subjected. Behaviorism is simply the most modern version of materialism, which asserts that all reality is physical. But according to our own analysis, the reality of the physical world is one the nature of which quite escapes us, so that the behaviorist—instead of providing psychology with a realistic subject-matter—actually forbids us to consider the most real of all things, our immediate experiences.

Suppose that we accept the definition of psychology as the science of experience *per se*. The question which arises first is as to what psychology is required to do with experience. Its initial problem, I should say, is that of giving a complete and accurate *description* of empirical reality. This description must be in terms of experience, exactly as "given," without addition or physical interpretation, and the process in which such a strictly empirical report arises is to be known as *introspection*. Introspection, in accordance with this definition, does not involve any inward turning of thought, in which the ego endeavors to see itself in a mental mirror. Introspection is simply empirical observation reduced to its lowest terms. It may seem strange to apply this name to the process of giving an account of visual or other seemingly external experiences, but if the account in question makes use of no terms which are not directly exemplified by the experiences, the usage is correct. So far as introspection is concerned, visual experiences are on the same plane as muscular or thought experiences.

The special nature of introspection will be made somewhat clearer if we note that the common-sense observer seldom introspects, or at any rate seldom intends so to do. In describing a visual experience, he would not confine himself to strictly empirical terms, such as color and visual depth, but would speak rather in terms of pigments, centimetres or other intentionally physical

factors. The common-sense observer is concerned with the supposed causes or conditions of his experiences and he automatically substitutes these causes for the concrete effects which are the only things actually given. As a matter of fact there is no common-sense vocabulary of pure experience, and one of the first and most difficult things which the psychologist must do is to develop a lexicon of strictly empirical concepts. The attempt to describe experience by using physical terms is known to psychologists as "the stimulus error." It is true that all of the physical terms which are employed by common-sense must ultimately be given a meaning in experience, but ordinarily this cannot be done in the actual experience which is immediately under consideration.

Another point which is to be noted regarding our definition of introspection is that it essentially involves the generation of a *description*. From a physical point of view, it might be called observation merely to *have* a certain visual or other experience. But for psychology this would merely mean that a certain experience *exists*, which provides data for introspection but cannot in itself constitute the latter. To the existing experience there must be added a further experience which describes the first one; then only do we have psychological observation. It is immaterial what kind of experience plays the part of the describer, so long as it sustains the proper relationship with the other experience to which it exclusively refers.

If the psychologist actually succeeds, through introspection, in giving a complete description of his experiences, without addition or subtraction or reference to any physical ideas, he may still find his thought beset by problems. He may wish to *explain* his experiences, which may consist merely in classifying them, but will more probably involve a search for their causes or conditions. Here he is evidently looking in the same direction as the physicist, but he will not necessarily see exactly the same things.

IV. THE INTERRELATIONS OF PSYCHOLOGICAL AND PHYSICAL FACTS.

When the psychologist inquires concerning the origin of his experiences, the first answer which he receives is that they are dependent upon the physical world. If I see a gray cat before me, this experience is said to be due to the actual presence of a physical

cat, *i.e.*, of a complex configuration of positive and negative electrical particles following the outlines of feline anatomy and physiology. The grayness of the cat is referable to the non-selective manner in which the electrons of the catskin reflect visible radiant energy, or "light." A somewhat different explanation must be given of the experience known as "a headache." This, too, can be referred to a material condition, such as a disturbance of circulation in the observer's brain membranes, but the cause and effect are very dissimilar and the cause is apparently incapable of operating upon more than one experience system, whereas the cat can be seen simultaneously by many observers.

However, the difference between these two cases is lessened when we further inquire by what means the physical (electrical) cat produces the cat experience, or the cat which is actually gray and cat-like. Experiment shows that no cat is given in experience unless radiant energy is reflected from the feline organism and enters the pupil of the observer's eye. It is true, further, that there is no cat in experience unless nerve currents are set up in the observer's optic nerve, and unless these currents arrive at his cerebral cortex. Even all this is not sufficient, for the currents must travel from receiving stations to central switchboards, or association areas, in the brain, before the cat experience arises. "Seeing a cat" physically involves this entire succession of physical processes, and the cat which is thus "seen" is not so much the phenomenon in experience as it is the feline constellation of protons and electrons which lies before the eye of the observer. To identify these two "cats," however, is quite impossible, since one is made of electricity and the other of color.

Here we have an opportunity to make a clear distinction between physical and psychological observation. The latter, as introspection, involves nothing more than the description of the cat as a phenomenon. The former, however, is essentially an attempt to describe the physical cat which lies before the eye. If no such cat is there to arouse the optic nerve currents and brain excitations by the normal course of events, there can be no question of physical observation. It is quite possible, however, even under such conditions, for the phenomenal cat to remain as a mere experience, and in this case the observer would be said to suffer an hallucination. No essential difference exists between an experience—cat having normal physiological accom-

paniments and a cat possessing an hallucinatory basis; both are equally good material for introspection.

If we follow the thesis of this paper, we may say that while introspection always endeavors to deal exclusively with the experience, physical observation (or inspection) uniformly tries to *depart* from the experience and to deal with the object which provides stimuli for our sense-organs. Just as the psychologist when he allows himself to refer to the object makes a "stimulus error," so the physicist, if he paid any attention ultimately to the experience, would be making an equally egregious "sensation error." This seems to me to provide us with an entirely workable distinction between physical and psychological observation, which harmonizes with actual usage and yet does not lead to a notion of introspection which is so subtle as to be meaningless. Such verbs as "to see," "to hear," "to touch," "to smell," "to taste," etc., may be taken as referring to special kinds of physical observation. If the cat is hallucinatory, we do not "see" it, because the eyes are not involved; we only "have" the cat.

It should be noted that, in accordance with this view, introspection is actually the first step in all physical observation, because the judgments made by the observer must be made directly upon the experience, which is the only reality actually accessible to his thought. However, he immediately discards the phenomenon and replaces it by its substitutes in the physical scheme, seeking ultimately an account which has no empirical terms.

The psychologist, for his part, has learned from the above considerations that his experience depends directly upon his higher brain activities and not upon the external objects which interest the ordinary physicist. If certain events occur in the brain, a gray cat is present in and as experience. A change in these events may make the cat green or turn it into a house. Usually such events are dictated by processes in more peripheral portions of the nervous system, and thence by objects in the outside physical world, but this is not necessarily the case, as *e.g.*, in dreams. However, it appears that a definite central brain condition is always required, and that experiences never exist without having this minimum physical accompaniment.

Recognizing this essential relationship, there are those who wish to *identify* the experience with the brain process or condition. Such an identification is obviously impossible. The

brain is a physical mechanism, composed only of electrons and protons arranged and moving in Einsteinian space and time. It has no color, no sound, no tactual character, no taste and no smell; it is even lacking in empirical extension and duration. Experience has all of these qualities. Even if we accepted an account of the brain mechanism written in the physics of five centuries ago, we could not identify anything with it except itself, *viz.*, the brain mechanism experience. There seems to be no way of getting "gray cats" into the brain. As a matter of fact the system of experience is utterly incommensurate with any physical system, and while the two must be correlated, the former can never be regarded intelligently as a part of the latter. It is much easier, as we shall see, to regard the latter as a portion of the former.

Thus we find ourselves face to face with what to me is the most stupendous mystery of science: The interdependency of our total experience and a minute portion of the physical world. In comparison with the magnitude of this mystery, the phenomena of apparent clairvoyance, telekinesis, materialization, etc., which are the psychophysical sensations of the day (at least among physicists), are as nothing. The alleged supernormal phenomena are difficult to find, and usually uncertain in demonstration, while the facts of brain psychophysics are with us in every conscious moment.

An exact understanding of brain mechanisms in terms of ultimate physics should eventually lead to a clear theory of the manner in which the factors of experience are related mathematically to those of the cerebral structures and processes. Even now we can formulate some interesting general principles along this line. We know that the brain is essentially a network of interconnecting nerve fibres. These fibres and their junction points are the seats of electrical disturbances which are at least partially under the control of the forces acting upon the sense-organs. In accordance with the general theory of matter, the brain substance as a whole must be composed of molecules, these in turn of atoms, and the latter finally of protons and electrons. The brain differs from other bodies of matter primarily in the particular manner of combination of its constituent particles. However, the special electrical conditions which exist in nerves must endow the brain mechanism with characteristics which are not commonly found in other bodies. The most important of these characteristics is probably the electrical "double layer" or

condition of "polarization" which follows the contour of the individual nerve fibres. This polarization surface may be considered to bind together electrically the states and processes of a large system of brain elements, producing a unified whole, which may be called the *central synergy*.

It seems very doubtful whether this synergy simultaneously involves all parts or levels of the brain. More likely, it is restricted at any moment to a fairly small area, located in one of the association regions of the cerebral cortex, and probably on the left-hand side of the brain in the normal right-handed individual. Its exact position will vary from moment to moment, following the variations of the nerve currents which are reaching it from the sense-organs. These fluctuations in position, resembling the wandering of a small spot of light over the brain surface, may also be correlated with the play of attention, on the psychological side. At each moment, regardless of its position, the central synergy is the point of convergence of all of the main incoming nerve currents, and is the point of divergence and control of the outgoing currents which are sent to the voluntary muscles of the body. It is the highest *focus* of nerve activities, occupying a position with respect to organic behavior similar to that which seems to belong to our introspective consciousness, or what we have previously designated as *experience*. On each brain surface upon which this synergy rests there is recorded an impress of its particular pattern, and this impress is the physical basis of memory. When we remember, or when a given form of experience is reproduced, the same brain structures are brought again into the same general state of excitation.

The functional units of the brain synergy must be the individual nerve fibres, or their junction points, which the physiologist knows as *synapses*. From the physical point of view these nerve units are extremely complex, but we are practically forced to suppose that their individual representatives in experience are the so-called "simple sensations." Accordingly, the structure of the brain synergy in terms of these nerve units would correspond to that of experience in terms of "simple sensations." For example, the experience which we call "an American flag" consists psychologically of three kinds of simple visual sensations called "red," "white," and "blue," respectively. The individual units or points of these sensations are arranged in the visual field in a definite pattern to constitute the "American flag experience."

In the brain synergy there must be a corresponding pattern of three different kinds of nerve structure or activity. This brain pattern will not necessarily take the geometrical form of an American flag, but it will be a definite sort which will always be reduplicated whenever the flag is given in experience.

The differences between "red," "white," and "blue," considered as elements of experience, must correspond to differences in molecular, atomic, or finer electrical structure within the so-called nerve units considered as individuals. What we call *quality* in experience is the correlative of *minute* structure or process in the brain. *Form* in experience corresponds with the grosser structure in terms of physiological rather than chemical or ultimate physical units. However, each experience has a quality "all its own," and it seems that whether a physical brain structure is represented in experience more by quality than by obvious form depends upon the strength of the electrical forces which bind the constituent parts together. A firm coherence of parts on the physical side goes with apparent simplicity and qualitative distinctiveness on the psychological side, while less coherent physical structures find natural parallels in the evident patterns of our immediate experience.

Time will not permit me to develop these conceptions in greater detail, but I trust that I have said enough to give you the impression that in the brain there is a physical mechanism which has a general form and activity corresponding at every moment to the form and activity of the individual experience. Ordinarily, we believe, there is only a single individual experience —such as yours or mine—corresponding to each brain. But in cases of so-called "dual personality" there are probably two distinct synergies in the same brain, so that two experiences are associated with a single organism. More than two are also apparently possible. In such cases of "dual" or of "multiple" personality, a contest naturally arises for control of the sensory and motor nerve currents, and the outcome of such a contest will determine the so-called "alternation of personality."

V. THE SOLUTION OF THE PSYCHOPHYSICAL RIDDLE.

Let us pause for a moment to consider how remarkable is the situation to which we are thus introduced. Everyone is familiar with the idea that "thought" and "consciousness" depend in a general way upon the brain, but as these notions are

ordinarily conceived they are much narrower than our conception of *experience*. Experience, for us, is not the "consciousness of the gray cat"; it *is* the gray cat so far as we have any immediate acquaintance with such an animal. Of course, the experience does not include the *physical cat*, because this is something which is inferred and is not a matter of direct empirical knowledge. Within experience lie not only those elusive phenomena of thought and feeling which are ordinarily identified with "mind," but the whole phenomenal world of common-sense: The universe as it is given to us, men, earth, stars and all. Why should these things be dependent upon a whirligig of electrons in our brains?

Why, indeed? Why should we, for a moment, be tempted to make the reality of experience secondary to that of any physical speculation? If we follow the almost inevitable methods of physical reasoning, we cannot escape conclusions similar to those which we have just outlined; if we accept brain physiology as a science we must accept its correlations with introspective psychology. Yet there are other solutions of the mystery besides that of regarding experience as a vaporous secretion or an "epiphenomenon" of the brain process.

The most universally accepted of these solutions among psychologists is one which can scarcely be called an *explanation*, because it simply adopts the apparent facts, themselves, as final. This is the theory of *psychophysical parallelism*, which states that experience and the brain mechanism have no actual interconnections through which any influence whatsoever can be transmitted from one to the other; but in spite of this fact they are related by mathematical laws which permit the nature of one to be predicted from a knowledge of the other. Following an old simile, experience and the brain synergy are like two perfect clocks which stay in perfect synchronism without the assistance of any interconnecting linkage. This doctrine of parallelism certainly represents a conceivable state of affairs, but not one which our reason can adopt as finally satisfactory. Fortunately, it is not the only remaining alternative.

The alternative which seems to me to be by far the most probable is one which, let me warn the reader at the outset, he will probably not understand. It is contained in a doctrine called *psychical monism*, which appears to be as subtle intellectually as Einstein's principle of relativity. Yet, like the latter, it is actually very simple and clear-cut in its fundamentals. With a

little effort, anyone should be able to follow the reasoning. Let us try.

Each thinker knows directly nothing but his own experience. The description of this, exclusively in its own terms, is psychology. By complicated processes of reasoning, the thinker arrives also at a description of his own physical brain synergy. If this description is couched in terms of modern physics, it is devoid of empirical meaning. Psychical monism provides it with meaning by affirming that the reality for which the physical description stands is none other than the thinker's total experience itself. It is thus evident why a detailed correlation must exist between the physical and psychological descriptions. They are two different ways of recording a single subject-matter. The psychological account is direct and indicates the inherent nature of the reality, while the physical account is indirect and is mainly concerned with its relations to other realities.

This explanation seems lacking in pregnancy when applied by a single thinker, A, to his own brain synergy, because no reason appears as to why the physical description should ever arise. The situation is clearer, although more complicated, when A considers the brain mechanism of another thinker, B. In this case the reality to which the physical description actually refers is B's experience, which is something quite separate from A's experience. A's symbolic physical scheme is then an attempt to arrive at a formula for a reality which lies outside of his own experience, following the true physical tradition. Hence he has not merely developed a misleading substitute for introspective observations. But it is still possible for him to obtain a description based upon the introspective method, if he will listen to the report which can be made by B.

Thus, in general, for all human brain synergies which we are forced to include in our physical system, we may postulate the existence of a corresponding number of human introspective experiences, and we may say that these experiences *are* the actual realities to which the respective physical descriptions refer. Although further investigation may reveal some specific reason why this interpretation should not be followed, such reasons are certainly not apparent in any data at present available. The physical description is patently without empirical meaning; it points insistently to some independent reality, but to what?

Physiological psychology reveals to us an undoubted and concrete existence which is part for part correspondent with this reality. If we refuse to identify this experience system with the system to which the physical description refers, we add a second profound mystery to that of the significance of our physics. If, on the other hand, we recognize in the so-called psychical or experience system, the long-sought-for reality of the universe, the two mysteries cancel one another and both are solved.

Still, as I have admitted, the doctrine is a difficult one to accept. If we grant that it is satisfactory for brain synergies, we still have before us the problem of the vast remainder of the physical universe. The tiny brain processes of even a billion human beings are as nothing in comparison with the whole system of which physics gives us an account. Yet, is it not possible that these minute instances may provide us, like "the flower in the crannied wall," with the key to the entire physical scheme of things? For my part, I believe that in this possibility is to be found the actual significance of our psychophysical knowledge. If human experiences were the only realities in the universe, it would perhaps be best to rely upon introspection to determine their nature, instead of employing the roundabout methods of physical investigation, since the physical account would always need reinterpretation through psychophysical formulæ. However, it seems that the universe has many parts which are inaccessible to the introspective method. Physics can provide us with the abstract equations for these mute existences, and through psychophysical interpretation we can ascertain their actual nature.

One way of looking at this situation is to say that physical investigation determines the *logical structure* of the universe, and does this with extreme accuracy; yet it fails to tell us anything concerning the concrete substance or concrete form of the reality with which it deals. In one single typical instance, these concrete aspects are presented directly to thought, namely, in human experience. If we can discover exactly how the physical scheme is related to the actuality in this single instance, it is possible that we shall be able to deduce, from this knowledge, relations which will apply to all conceivable instances. In a similar manner, the great scientific discoverers have succeeded with simple apparatus in demonstrating principles which apply to all portions of the physical system, however great or small.

The conception of the real universe which develops from these principles is one of a world of pure experience. However, this experience is split up into a vast number of interacting parts, some firmly and others loosely bound together. Among these many experience systems, the human introspective fields occupy positions which are homologous with those held by the corresponding human brain synergies in the physical scheme. It is for this reason that human experience is influenced in definite ways by all other portions of the universe, and is led to mirror the whole system in the elaborate doctrines of modern physics.

Spectrophotometric Methods for Investigating Dye Stuffs in Fabrics by Means of Transmitted Light. N. USPENSKI and G. WORONKOFF, Moscow. (*Zeit. f. Phys.*, **17**, No. 2.)—In attacking this problem Formanek dissolved the coloring matter in an appropriate solvent and examined the transmitted light with a spectroscope. The weakness of the method lies in the difference which may exist between the dye in the fibre and the same dye in solution. Poray-Koschuetz and Auschkop employed a spectrophotometer with two slits. Through one came light reflected from the dyed fibres and through the other light reflected by the uncolored fibres. From the intensities of light with any wave-length coming through the two slits it was possible to deduce the absorption of that particular kind of light by the dye. Unfortunately the uneven structure of the surface of the fabric introduces uncertainties into the observations.

The special problem confronting the authors was how to use a Koenig-Martens polarizing spectrophotometer for the investigation of light transmitted through the dyed fabrics. The opacity of the fibres was overcome by surrounding them with a medium having the same index of refraction. The transmitted light was not of uniform intensity across the cross-section of the beam. Uniformity was secured by rotating the mass of fibres. The polarization produced in the fibres was found not to interfere in the investigation.

The results are presented by tabulating the wave-length at which maximum absorption takes place for about two dozen dyes. Where data are given for silk and for cotton colored with the same dye this wave-length is nearer to the red end of the spectrum for wool than for cotton in all but one instance. The number of cases where this comparison can be made is, however, small.

The work was carried out in the physical laboratory of the Karl Marx Institute. G. F. S.

ON STRESSES IN A PLATE WITH A CIRCULAR HOLE.*

BY

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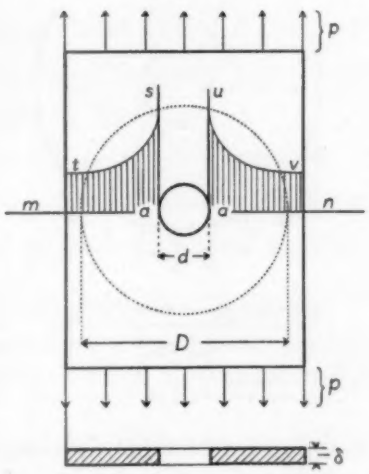
(1) THE problem of the distribution of stresses in the immediate neighborhood of a hole in a thin extended plate has been completely solved for several shapes of holes, for instance, in cases of circular [1] and elliptical [2] holes.

These solutions show that the great "local stresses" are set

FIG. 1.



up at the edge of the hole. In order to reduce these stresses it is common practice to reinforce a hole with a bead.

In this paper a method is given to approximate the influence of the above-mentioned beads on the local stresses.

(2) First we will consider the simplest case, that of a plate (Fig. 1) with a small circular hole, the plate itself being subjected

* Communicated by the Author.

[1] Kirsch, *Zeitschr. d. Ver. d. Ing.*, 1898.

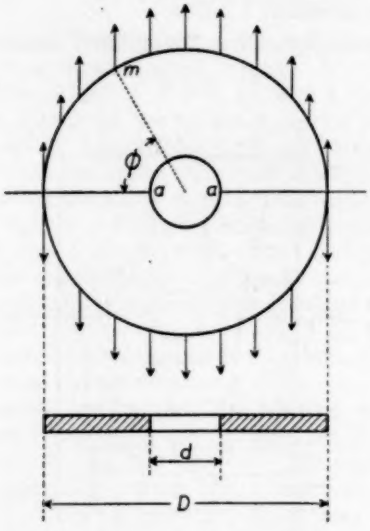
[2] G. Kolosoff, St. Petersburg, "Dissertation," 1910, and C. E. Englis, *Engineering*, 1913, p. 415.

at its upper and lower boundary to uniformly distributed tension p.

It is known that a hole causes distortion of the stress distribution in its immediate neighborhood in such a manner that, for instance, stress distribution over the cross-section mn will be as shown by the curves s-t and u-v. The magnitude of the stress at a-a is $3p$ [3].

It is further known that if a circle of the diameter D is considered, the stresses at the points of the circumference are not materially affected by the presence of a hole, provided that D is large compared with the diameter of the hole d.

FIG. 2.



Considering, therefore, the portion of the plate bounded by a cylindrical surface of diameters D and d, the stresses at any point may be assumed as caused by the forces corresponding to the tension p as shown, for example, in Fig. 2.

It is easy to see that the force per unit length at any point m of the outer boundary will be $\delta p \sin \phi$. In this manner the problem is reduced to that of an annular ring subjected at its outer boundary to the given forces. The maximum stresses $p_{max.}$ at the

[3] The width of the strip is assumed large compared with the diameter "d" of the hole.

points a, a, due to these forces, can be approximately calculated without difficulty by using the elementary theory of the bending of curved bars [4] (Appendix I).

In Table I, the values of the ratio $p_{max.} : p$ calculated in this manner for different values of $\frac{D}{d}$ are given.

TABLE I.

$\frac{D}{d} =$	3	4	5	6	8	10
$\frac{p_{max.}}{p} =$	3.83	3.26	3.08	3.03	3.09	3.30

By comparison with the results of the exact theory, we find that for $5 < \frac{D}{d} < 8$ the results obtained agree closely with exact solution for a small circular hole.

When $\frac{D}{d} < 5$, the hole has a perceptible effect on the distribution of the forces acting on the external boundary of the ring, and as a result of this we obtain some increase of the ratio $\frac{p_{max.}}{p}$.

The increase of the same ratio in the cases, when $\frac{D}{d} > 8$, is the result of insufficient accuracy of the elementary theory of curved bars when the inner radius is very small in comparison with the outer one.

(3) We will now use the same approximate method in the case of a hole with a bead (Fig. 3). We may expect that the bead diminishes the sphere of perceptible influence of local stresses and in such a manner as to make the approximate method more satisfactory. The calculations worked out for the case shown in the Fig. 3, when $\frac{b}{\delta} = 11$ and $\frac{a}{d} = 0.01$, gives us the following values of the ratio $\frac{p_{max.}}{p}$ for various values of $\frac{D}{d}$:

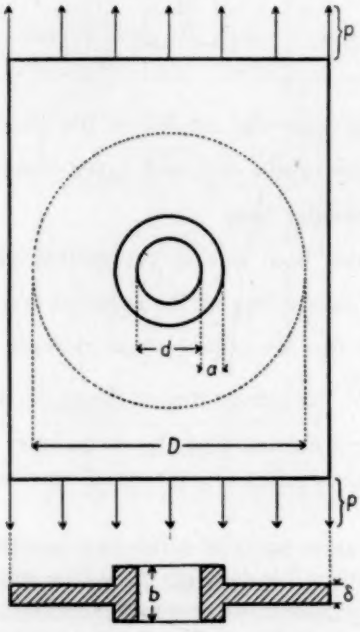
[4] By using the exact solution of the two-dimensional problem of elasticity for a circular ring, the Kirsch's solution above mentioned can be obtained. See author's paper, *Bull. Inst. Polyt. of Kieff*, 1907.

TABLE II.

$\frac{D}{d}$ =	4	5	6
$\frac{p_{max.}}{p}$ =	2.56	2.53	2.56

It is seen that the ratio $\frac{p_{max.}}{p}$ varies but slightly with $\frac{D}{d}$, *i.e.*, the stresses near a hole are of local character.

FIG. 3.



Taking this into account we have made further calculations for the case $\frac{D}{d} = 5$ only.

Denoting by F_1 the diminution of the cross-section of the strip, due to the hole, and by F_2 the cross-section of the bead, we have:

$$F_1 = d.\delta, \quad F_2 = (b - \delta).a,$$

from which, taking $a = 0.01d$, we obtain

$$\frac{b - \delta}{\delta} = 100 \frac{F_2}{F_1}.$$

Increasing the dimension b, we study the influence of the variation of the cross-section of a bead on the maximum value of the local stresses.

The results obtained in such a way are given in Table III.

TABLE III.

$\frac{b-\delta}{\delta} = 100\frac{F_2}{F_1} =$	10	20	30	40	50
$\frac{p_{max.}}{p} =$	2.53	2.17	1.90	1.69	1.53

We see that maximus stresses decrease as F_2 increases.

(4) The results obtained can be used also in the cases of other shapes of cross-section of the beads, provided only that the dimension a of the bead in the radial direction can be considered small in comparison with the diameter d of the hole (Appendix II).

We take, as an example, a plate in tension, 1 cm. thick, with a circular hole of 1 m. diameter.

Let the edge of the hole be stiffened with two iron angles $10 \times 10 \times 1$ cm. (the cross-section of Fig. 6).

In such a case $F_1 = 100$ cm.^{2}, $F_2 = 20 \times 2 = 40$ cm.^{2} and $100\frac{F_2}{F_1} = 40$.

From Table III we obtain for this case $\frac{p_{max.}}{p} = 1.69$.

The more detailed calculations for this case, where the shape of the cross-section is taken into account (Appendix II), give us

$$\frac{p_{max.}}{p} = 1.73.$$

The error of the result obtained from Table III is, as we see now, only 2 per cent.

(5) The approximate method outlined here can be developed also for any other shape of a hole, for instance, in the case of an elliptical hole.

The thin plates, which are in a state of stress other than simple tension, can be considered in the same manner.

We can, for instance, consider the case of a plate submitted to shear or bending in its plane. It is necessary only to calculate

corresponding distribution of tractions along the outer boundary of the ring.

APPENDIX I.

In considering the ring, cut out from an extended strip (Fig. 2), we take account of the symmetry and consider one quadrant only (Fig. 4).

The maximum stress takes place at the point n of the horizontal cross-section mn. From the equation of equilibrium we

FIG. 4.

conclude at once that the longitudinal force at the cross-section mn is equal to $\frac{1}{2}\delta D.p$. The corresponding tensile stress is

$$p_1 = \frac{p.D}{2.h},$$

where h denotes the width of the ring.

The value of the bending moment M_0 in the same cross-

section can be calculated from the condition that, as a result of symmetry, this cross-section retains its horizontal direction.

Denoting by M the bending moment in any cross-section $I-I$, by N the longitudinal force in the same cross-section, and by γ the distance of the centre of the cross-section from the neutral axis, when a curved bar is bent by terminal couples only—the condition, expressing that the cross-section mn does not rotate, can be written as follows:

$$\int_0^{\frac{\pi}{2}} M d\phi - \gamma \int_0^{\frac{\pi}{2}} N d\phi = 0 \qquad (a)$$

where the first member on the left is proportional to the rotation of the cross-section mn with respect to the cross-section st, produced by the bending moment M, and the second is proportional to the rotation, due to longitudinal force N.

Considering all the forces acting on the part $mn\ II$ of the ring, we find that for the cross-section $I-I$ the longitudinal force is

$$N = \frac{1}{2} \delta D . p . \cos^2 \phi \qquad (b)$$

and bending moment

$$M = M_o + \frac{1}{2} p D \delta (1 - \cos\phi) \left[\frac{1}{4} D (1 - \cos\phi) + \frac{1}{2} h \cos\phi \right] \qquad (c)$$

The distance γ in the case of a rectangular cross-section is represented by the well-known formula

$$\gamma = \rho - \frac{h}{\log_n \frac{D}{d}} \qquad (d)$$

where ρ denotes the radius of the centre line of the ring (Fig. 4). Substituting (b), (c) and (d) in equation (a) and performing the integration, we obtain

$$M_o = \frac{1}{2\pi} p . \delta . D^2 \left[(\pi - 2) \frac{\rho}{D} + \frac{\pi}{2} \cdot \frac{\gamma}{D} - \left(1 - \frac{1}{4}\pi \right) \frac{h}{D} - \frac{3}{8}\pi + 1 \right] \qquad (e)$$

Now, the corresponding stresses can be calculated from the known formula for curved bars

$$p_z = \frac{M}{S} \cdot \frac{z}{r - z} \qquad (f)$$

where:

S denotes the moment of the cross-section about the neutral axis,
r is the distance of the neutral axis from the centre of the ring (Fig. 4),
z is the distance of the point under consideration from the neutral axis,
z is considered positive when measured towards the centre of curvature.

For the cross-section mn and the point n we have

$$M = M_0$$

$$z = \frac{h}{2} - \gamma, r - z = r + \gamma - \frac{h}{2} = \frac{d}{2}$$

and

$$S = h\delta\gamma$$

Substituting this in (f), we obtain

$$p_2 = M_0 \frac{1}{\gamma\delta d}\left(1 - 2\frac{\gamma}{h}\right)$$

Adding this stress to the tensile stress p_1, due to the longitudinal force, we obtain the complete stress at n, which represents the maximum stress

$$p_{max.} = p_1 + p_2$$

The results of calculations made in such a way for different values of the ratio $\frac{D}{d}$ are given in Table IV.

TABLE IV.

$\frac{D}{d} =$	3	4	5	6	8	10
$\frac{2\gamma}{h} =$	0.1796	0.2238	0.2574	0.2838	0.3239	0.3536
$\frac{p_1}{p} =$	1.50	1.33	1.25	1.20	1.14	1.11
$\frac{p_2}{p} =$	2.33	1.93	1.83	1.83	1.95	2.19
$\frac{p_1+p_2}{p} =$	3.83	3.26	3.08	3.03	3.09	3.30

APPENDIX II.

In the case when the edge of the hole is reinforced with a bead (Figs. 3 and 4), we use the same equation (a). In the equation (c) it is only necessary to put instead of $\frac{h}{2}$ the distance

c_2 of the centre line from the external edge of the ring and to take an appropriate expression for γ.

Denoting

$$\frac{b}{\delta} = n; \frac{a}{d} = m,$$

we obtain from Fig. 5:

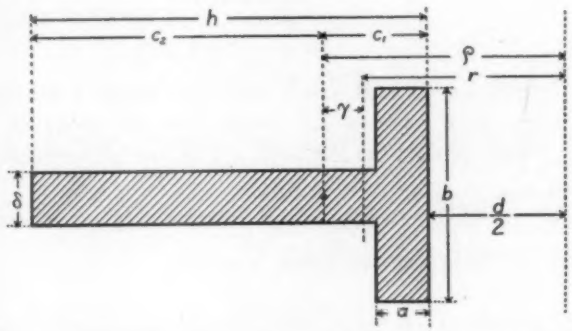
$$\frac{h - c_2}{d} = \frac{c_1}{d} = \frac{h}{2d} \cdot \frac{1 + (n-1)\frac{m^2 d^2}{h^2}}{1 + (n-1)\frac{md}{h}} \qquad (g)$$

The usual method of determining the position of the neutral axis gives us

$$\frac{\gamma}{d} = \frac{\rho - r}{d} = \frac{\rho}{d} - \frac{(n-1)m + \frac{h}{d}}{(n-1)\log_n(1+2m) + \log_n \frac{D}{d}} \qquad (k)$$

Denoting by F the area of the cross-section of the ring, we

FIG. 5.



obtain the tensile stress, due to the longitudinal force in the cross-section mn, equal to

$$p_1 = \frac{1}{2} \cdot \frac{p.D.\delta}{F}.$$

The stress p_2 at the point n, due to bending, calculated from (f), is:

$$p_2 = \frac{M_0}{F\gamma} \cdot \frac{2(c_1 - \gamma)}{d}$$

The complete stress at the point n is:

$$p_{max.} = p_1 + p_2.$$

The results of calculations made in such a way for the case $n = 11$, $m = .01$ and different values of the ratio $\frac{D}{d}$ are given in Table V.

TABLE V.

$\frac{D}{d}$	$\frac{c_1}{d}$	$\frac{\rho}{d}$	$\frac{c_2}{d}$	$\frac{\gamma}{d}$	$\frac{p_1}{p}$	$\frac{p_2}{p}$	$\frac{p_1+p_2}{p}$
4	0.703	1.203	0.797	0.1935	1.25	1.31	2.56
5	0.953	1.453	1.047	0.2907	1.19	1.34	2.53
6	1.202	1.702	1.298	0.3956	1.15	1.41	2.56

When m is a small quantity we can use, instead of (g) and (k), the following approximate formulæ:

$$\frac{c_1}{d} = \frac{h}{2d}\left[1 - (n-1)\frac{md}{h}\right] \tag{g'}$$

$$\frac{\gamma}{d} = \frac{\rho}{d} - \frac{(n-1)m + \frac{h}{d}}{2m(n-1) + \log_n \frac{D}{d}} \tag{k'}$$

The quantities m and $n-1$ enter in these formulæ as the product term $m(n-1)$ only. From this we conclude that the stress $p_{max.}$ will depend on the area F_2 of the cross-section of the bead only.

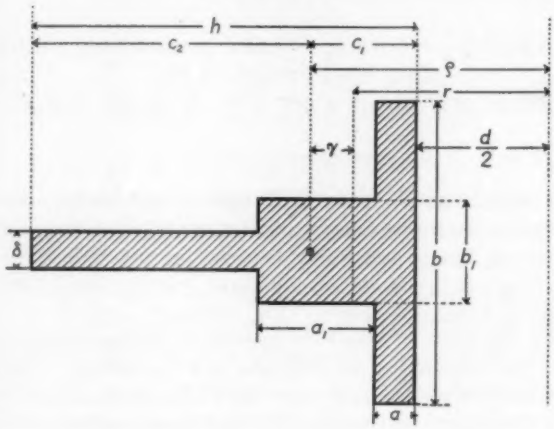
Taking $m = 0.01$ and varying the quantity n, we obtain for $\frac{D}{d} = 5$ the results given in Table VI.

TABLE VI.

$n-1$	$\frac{c_1}{d}$	$\frac{\rho}{d}$	$\frac{\gamma}{d}$	$\frac{c_2}{d}$	$\frac{p_1}{p}$	$\frac{p_2}{p}$	$\frac{p_1+p_2}{p}$
20	0.9095	1.4095	0.312	1.0905	1.14	1.03	2.17
30	0.8703	1.3702	0.326	1.1297	1.09	0.81	1.90
40	0.8342	1.3342	0.334	1.1658	1.04	0.65	1.69
50	0.8010	1.3010	0.339	1.1990	1.00	0.53	1.53

In the case of a bead consisting of the two iron angles, the cross-section of the ring has the shape represented in Fig. 6.

FIG. 6.



Using the notation:

$$\frac{b}{\delta} = n; \frac{a}{d} = m; \frac{b_1}{\delta} = n_1; \frac{a_1}{d} = m_1,$$

we obtain the position of the centre of gravity from the formulæ:

$$\frac{c_1}{d} = \frac{h}{2d} \cdot \frac{1 + (n-1) + \frac{m^2 d^2}{h^2} + (n_1 - 1)\frac{m_1 (m_1 + 2m) d^2}{h^2}}{1 + m(n-1)\frac{d}{h} + m_1 (n_1 - 1)\frac{d}{h}} \qquad (l)$$

The position of the neutral axis is given by the formula:

$$\frac{\gamma}{d} = \frac{\rho}{d} - \frac{\frac{h}{d} + m(n-1) + m_1 (n_1 - 1)}{(n-1)\log_n (1+2m) + (n_1 - 1)\log_n \frac{1 + 2m + 2m_1}{1 + 2m} + \log_n \frac{D}{d}} \qquad (s)$$

When $m_1 = 0$; $n_1 = 1$, these formulæ coincide with formulæ (g) and (k).

We have made the calculations for the case where

$$n = 21, n_1 = 3, m = 0.01, m_1 = 0.1, \frac{D}{d} = 5.$$

This is true for the plate previously considered: Thickness = 1 cm., hole diameter—1 m. and bead cross-section consisting of the two angles 10 × 10 × 1 cm.

The results obtained are:

$$\frac{c_1}{d} = 0.8388; \frac{\gamma}{d} = 0.323; p_1 = 1.04p; p_2 = 0.69p; p_{max.} = 1.73p.$$

This differs only about 2 per cent. from the results given by Table III.

Boring-insects as Factors in Tropical Industries.—It has long been known that many species of insects exist which make their nests by boring wood, but it has lately become known that some of these can bore through soft metals, such as lead, and do considerable injury to lead-incased telephone wires. The warmer portions of the world are naturally the most infested by insects of all types; the number of species and the enormous prolificness are appalling. The teredos, which bore submerged timber, are very destructive, but have been measurably combatted by treating the timber with poisonous solutions.

H. F. Dietz and T. E. Snyder, of the U. S. Bureau of Entomology, have made extensive studies of a very destructive type of boring-insects—the termites—often called "white ants." Their investigations were limited to Panama, and a summary of their results appears in *Jour. Agric. Res.* (1923, **26**, 279). Many species exist in the region. They are "social insects," that is, live in large nests in great numbers, and are specialized as to the functions necessary to the maintenance of the community. There are workers and soldiers, the latter provided with formidable jaws and a venom-secreting gland. This venom, though apparently not capable of seriously affecting human beings, has a paralyzing action upon other insects. The workers and soldiers are presumably sexless as occurs among bees and ants. Dietz and Snyder detail many striking features of the insect life, and give photographs showing appearance and construction of nests and damage done by the borers. They are capable of riddling completely *Lignum vitæ*, the hardest wood of the tropics. Lead sheathing for cables has also been perforated. Ordinary tarring of the outside of timber is no protection. At certain periods, the insects develop wings and fly about in great numbers rendering life in the districts almost unbearable. Much of the damage done undoubtedly arises from the happy-go-lucky methods of life in the tropics, and from the disturbance of the balance of nature by human interference, such as cutting away the forests and diminishing the number of small, insectivorous birds. Concrete and steel constructions are proof against the boring, but are necessarily very expensive. H. L.

THE OPTICAL PYROMETER AS A BRIGHTNESS PHOTOMETER.*

BY

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ALL optical pyrometers are photometers in that the condition of balance consists in bringing two adjacent surfaces to the same brightness. Two distinct differences between the pyrometer and photometer may be noted. In the first place the pyrometer is constructed and used so that the brightness (light emitted per unit area) of the surface studied is measured rather than the total light emitted. The second difference is that with the pyrometer practically all color differences are avoided by the use of a so-called monochromatic screen before the eyepiece. This monochromatic screen may be any color, and if the relative brightnesses of a black body are measured at two temperatures the ratio found will of course depend upon the monochromatic screen used.

A diagram showing the arrangement used in the disappearing filament optical pyrometer is given in Fig. 1. The comparison source is the filament of the pyrometer lamp *D* which is placed in the plane where the image of the source studied is brought to a focus by the objective lens *B*. Brightness matches are made by varying the current through the filament of the pyrometer lamp until it matches in brightness the image of the source studied, *A*. The brightness matches are made by observations upon the pyrometer filament as it is seen crossing this image of the background through the eyepiece *F*. The monochromatic screen is generally placed at *G*.

Crova and others have shown that the relative brightness of a black body for different temperatures varies in the same ratio as the brightness of some particular wave-length interval near the centre of the visible spectrum. This wave-length is not constant, but varies so that the Crova wave-length becomes shorter for higher temperatures.

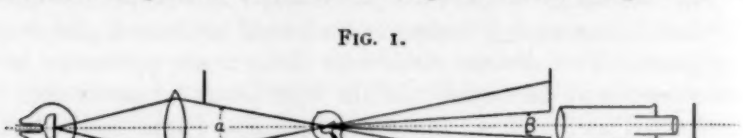
* Communicated by the Author.

The Crova wave-length was calculated by means of the following formula:

$$(1) \qquad \frac{\int_0^\infty J(\lambda T_1)\, V_\lambda d\lambda}{\int_0^\infty J(\lambda T_2)\, V_\lambda d\lambda} = \left[\frac{J(\lambda T_1)}{J(\lambda T_2)}\right]_{\lambda_c}$$

where $J(\lambda T)d\lambda$ is the energy as given by Wien's equation for the wave-length interval λ to $\lambda + d\lambda$ and V_λ the visibility, and the results were plotted as shown in Fig. 2. This integral can be

FIG. 1.



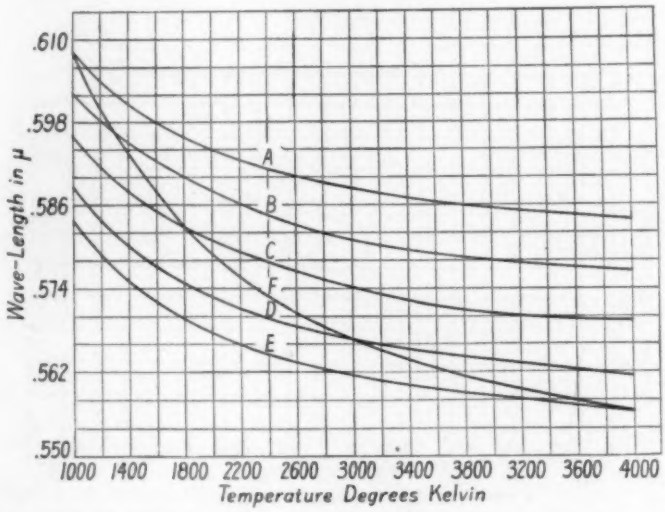
Drawing showing arrangement of parts of a disappearing filament optical pyrometer. (A) Source studied, (B) objective lens, (C) entrance cone diaphragm, (D) pyrometer filament, (E) eyepiece diaphragm, (F) eyepiece, (G) monochromatic filter.

calculated by the step-by-step method with sufficient accuracy for this purpose.

Curve F (Fig. 2) is the limiting Crova wave-length. This limiting wave-length is the value that the Crova wave-length approaches as the two temperatures approach each other. The value of the total light emitted changes at the same rate at this temperature as does the value of the spectral brightness for this wave-length. To show how these curves may be used the Crova wave-lengths for a couple of temperature intervals will be found. The Crova wave-length between 1800° K. and 2900° K. is given by the ordinate of the point where the 1800° K. curve crosses the 2900° K. curve ordinate, that is, it is 5749μ. For the range between 2100° K. and 2900° K. the effective wave-length is likewise given by the point where the 2100° K. curve would cross the 2900° K. ordinate. However, in this case the 2100° K. is not drawn, but will have to be imagined as drawn parallel to the 1800° K., one point of its position being determined by where the curve E crosses the 2100° K. ordinate. The Crova wave-length for this interval is 5722μ. These Crova wave-lengths could have been obtained from curve F by taking the mean of the limiting Crova wave-lengths for the two temperatures.

If it were possible to obtain a monochromatic screen whose effective wave-lengths for different temperature intervals were the same as the Crova wave-length, a pyrometer with such a screen would in general make a very good brightness photometer. By the use of this screen, the pyrometer could be used as a regular photometer, for measurements where large color differences are encountered. Even if it is not possible to get a screen that will

FIG. 2.



Crova wave-lengths. Curve A, Crova wave-length from 1000°K. to other temperatures. Curve B, 1300°K. to other temperatures. Curve C, 1800°K. to other temperatures. Curve D 3000°K. to other temperatures. Curve E, 5000°K. to other temperatures. Curve F, limiting Crova wave-length.

give the exact wave-length, one might be found so that the error due to variations in the wave-length used would be less than the error in ordinary photometers for large color differences.

In using the pyrometer it is the integral luminosities through the glass screen that are compared, and for this reason the effective wave-length of the glass screen for a certain temperature interval has been defined as the wave-length such that for the definite temperature interval for a black body, the ratio of the radiation intensities for this wave-length shall equal the ratio of the integral luminosities through the screen used. The effective

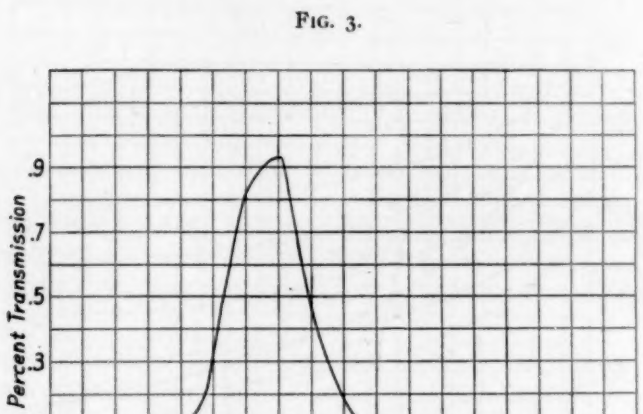
wave-length of a monochromatic screen is calculated by means of the following formula:

$$(2) \qquad \frac{\int_0^\infty J(\lambda T_1)\, t_R V_\lambda d_\lambda}{\int_0^\infty J(\lambda T_2)\, t_R V_\lambda D_\lambda} = \left[\frac{J(\lambda T_1)}{J(\lambda T_2)}\right]_{\lambda_1 e}$$

where the symbols have the same meaning as given above and t_R is the spectral transmission of the screen.

A screen consisting of two pieces of unsaturated green glass

FIG. 3.



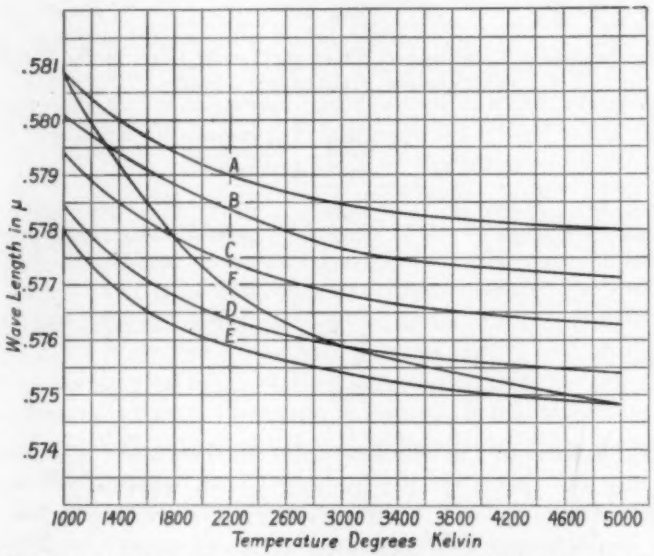
Spectral transmission of special screen made up of a combination of a piece of green glass and a piece of Corning high transmission 400 per cent.

and a piece of Corning high transmission red, 400 per cent., was tested out as a screen on an optical pyrometer used as a brightness photometer. The spectral transmission of this combination screen is shown in Fig. 3. As can be seen from the curve the transmission is very low. It would be much better if a screen could be found that had a higher transmission without at the same time broadening the transmission band. The effective wave-lengths of the screen were calculated by means of equation 2 and the results plotted as shown in Fig. 4. The use of these curves is the same as was illustrated for those of the Crova wave-lengths. It will be seen that the effective wave-lengths of the glass combination

have about the same values as the Crova wave-length for the same temperature interval.

To use a pyrometer as a photometer, it is necessary to have it calibrated for either relative or actual brightnesses rather than for temperature. This calibration can be obtained from a number of standards of brightness or from a single standard of bright-

FIG. 4.



Effective wave-length of special screen whose spectral transmission is shown in Fig. 2.
Curve A effective wave-length from 1000°K. to other temperatures.
" B " " " " 1300 " " "
" C " " " " 1800 " " "
" D " " " " 3000 " " "
" E " " " " 5000 " " "
" F limiting effective wave-length.

ness. In the latter case the apparent brightness of the standard can be reduced by the use of a number of rotating sector discs in turn between the source and the pyrometer lamp, thus allowing calibrations of the pyrometer lamp at different brightnesses.

From Wien's equation it can be shown that the relative change in the ratio of the spectral brightnesses of a black body for a particular temperature range for a change in wave-length is given in the following equation:

(3) $$\frac{dR}{R} = -\frac{d\lambda}{\lambda}\log_e R$$

where R is the ratio of brightnesses and λ the wave-length. Applying this equation to the change from the Crova wave-length to the effective wave-length of the special monochromatic screen, the percentage error that would result from a use of the screen in connection with brightness measurements for color differences corresponding to different temperature intervals was found and the values given in Table I.

TABLE I.

Errors in Brightness Measurements Using the Special Glass in the Pyrometer for Different Temperature Ranges.

T_1	T_2	Crova Wave-length.	Effective Wave-length of Glass Screen.	Error.
1000° K.	5000° K.	.5838μ	.5778	+20.2 per cent.
1600	5000	.5717	.5766	−9.1
1600	3000	.5765	.5771	− .7
1800	3000	.5742	.5768	−2.5
1800	2400	.5773	.5772	.0
2500	2800	.5696	.5762	−1.3
2800	5000	.5625	.5754	−9.2
2500	5000	.5635	.5756	−10.8

A comparison of the two sets of curves shown in Figs. 2 and 4 shows that the curve for the limiting Crova wave-length would cross the curve for the limiting effective wave-length for the special monochromatic screen used at about 2100° K. It has been found that the effective wave-length between two temperatures is given with sufficient accuracy for purposes of calculation by the mean of the values of the limiting effective wave-lengths for the two temperatures. This relation has also been found to hold for the Crova wave-length. From this relation and the position of the curves for the limiting effective wave-length and the limiting Crova wave-length there can be found certain temperature ranges for which the Crova wave-length equals the effective wave-length of the screen used. One temperature interval for which this is practically true is 1800° K. to 2400° K., both wave-lengths being very nearly 0.5772μ. For such temperature ranges there would, of course, be no error in brightness measurements with the pyrometer using the glass screen.

From the values given in Table I it can be seen that the error

in any case that might be met with in practice is not large. If the brightness of a surface illuminated with sunlight (color temperature, 5600° K. at the earth's surface) is compared with the brightness of the same surface illuminated with a gas-filled tungsten lamp (color temperature about 2800° K.) the error would be only about 11 per cent. If the surface was illuminated with an ordinary tungsten lamp (color temperature, 2500° K.) the error would be 12.5 per cent., when this was compared with the same surface illuminated by sunlight.

Several tests were made of the above described use of the pyrometer as a photometer. In the first test the pyrometer was used to measure the relative brightnesses of a black body at different temperatures. The brightness of the black body at different temperatures was known from some other work. The known value of the brightness of the black body was plotted against the relative brightness as obtained from the measurements with the pyrometer. If the brightnesses obtained with the pyrometer using the special screen are proportional to the candle-powers of the black body, the curve thus obtained should be a straight line. It was found that this relation was represented by practically a straight line for a temperature range from 1600° to about 2700° K. This test gave a good calibration of the pyrometer for actual brightnesses.

For the second test four pieces of paper of different colors were illuminated with a gas-filled tungsten lamp and set at such distances from the lamp that they each had the same brightness as determined with a Macbeth photometer by a number of readings by two observers. The brightness of these papers was then measured with the pyrometer, using the combined red and green glass before the eyepiece. Below are given the data on the relative brightnesses, which represent the average of two sets of about six readings each.

White.	Blue.	Green.	Red.
100	97.6	97.6	97.3

In the third test the ratio of the brightness of a ribbon tungsten lamp was measured for two temperatures (1700° and 2800° K.), first with the regular photometer and then with the

pyrometer. The measurements with the regular photometer gave a ratio of 407 for these two brightnesses. The value of the ratio obtained with the pyrometer for this same range was 411 as the average of readings by two observers.

For the fourth test of the pyrometer as a brightness photometer, the brightness of clean snow on which the sun was shining was measured. This gave 2.12 candles per square centimetre as against the value of 2.20, which was obtained with the Macbeth photometer. No corrections have been made in any of the above tests for the error due to the known difference between effective wave-length and the Crova wave-lengths.

To find out how different observers would agree in the use of the pyrometer as a photometer, the pyrometer was calibrated as a brightness photometer by one observer and the following experiment made. A clean magnesium carbonate surface was illuminated by means of a gas-filled tungsten lamp and the brightness of this surface measured with the pyrometer by several observers, each observer making readings on at least two different days. The average results for the different observers are given in Table II.

TABLE II.

Results by Different Observers.

Observer.	Brightness in candles/cm.²
F	0.300
C_1	.309
M	.311
G	.308
H	.297
C_2	.299
W	.292
S	.296

Part of these were inexperienced observers and those that had had experience were known to differ several per cent. for a marked color difference. These readings agree much better than corresponding readings with a regular photometer where the color difference corresponds to that between the ordinary tungsten standards and the gas-filled lamp.

If the color temperature of the source or surface studied is

known, it is of course possible to correct the values obtained with this pyrometer to the values that would be obtained, using the correct Crova wave-length. This has been done in all cases where this pyrometer has been used to obtain brightnesses of sources at surfaces just mentioned where the color temperature is known.

The disappearing filament pyrometer, with red-green glass in the eyepiece, has been found very satisfactory as a photometer for measuring the brightness of different surfaces that were difficult to measure by ordinary means.

The Dielectric Constants and Absorption Coefficients of Alcohols. G. POTAPENKO. (*Zeits. f. Phys.*, Dec. 12, 1923.)—This series of experiments was made only with electric waves ranging in length from 30 to 90 cm., and with methyl and ethyl alcohols. For methyl alcohol the dielectric constant showed no great change over the range of wave-lengths used, but the absorption coefficient varied greatly. It increased quite regularly as the wave-length became less. At about the same temperature this coefficient had the value of .385 for the wave-length 33.34 cm. and .057 for 89.74 cm. In the case of ethyl alcohol the coefficient again grew greater as the length of wave employed was reduced and for a length of 29.4 cm. it was found to be no less than .843. "It approaches the absorption coefficients of metallically reflecting bodies." With this alcohol there is, further, a marked diminution of the value of the dielectric constant as the wave-lengths are diminished. At lengths of 29.4 and 89.7 cm. the values are 4.44 and 20.9, respectively. This indicates anomalous dispersion.

These experiments were performed at the Physical Institute of the University of Moscow and were presented to the Lebedew Physical Society of Moscow. G. F. S.

The Luminescence of Titanium Oxide. E. L. NICHOLS. (*Phys. Rev.*, Nov., 1923.)—An oxy-hydrogen flame impinged on a quantity of this oxide in a crucible. The amount of free oxygen in the flame had much to do with the resultant color. "In fact at any temperature between the red heat and 1200° the color of a mass of the incandescent oxide upon which an oxy-hydrogen jet impinges, may be changed from a deep red to a blue by a very slight adjustment of the gases in the flame." A study of both of these states was made. For both "the remarkable fact is that the radiation from this oxide throughout the visible spectrum is in excess of black-body radiation for the whole range of temperatures from the threshold of visibility to 1200° C." The ratio of the intensity of light actually emitted to the intensity of light emitted by a black body at the same temperature ranges from 153.1 to a trifle over unity. G. F. S.

The Validity of Ohm's Law in Electrolytes When the Field Strength is Great. MAX WIEN. (*Ann. d. Phys.*, Vol. 73, 1924, p. 161.)—For a fall of potential in the electrolyte of one volt per cm. a sodium ion travels 1.6 cm. per hour; a chlorine ion, 2.5, and a hydrogen ion, 11.7 cm. per hour, the temperature being 18° C. For such small speeds no trace of departure from Ohm's law has been detected, but it might well be otherwise for a fall of potential amounting to a million volts per cm. when the hydrogen ion should move with the speed of an express train. To investigate this question the investigator has studied the momentary discharge of a condenser through an electrolytic cell. Solutions of NaCl, $KHSO_4$, H_2SO_4, and NaCl with sugar were used. He concludes: "By these experiments I believe I have proved that up to field strengths of 500,000 volts per cm. Ohm's law holds in electrolytes within 1 per cent."

G. F. S.

The Discontinuity of the Hydration Process. W. A. DAVIS and J. V. EYRE. (*Proc. Roy. Soc.*, A 727.)—"At the Linen Industry Research Institute, Belfast, where the work to be described was undertaken, the study of the absorption of moisture by textile materials has naturally occupied attention." The substance under investigation was carefully dried, then it was exposed to moist air at constant temperature and humidity and its weight was taken at frequent intervals. The process as observed is not at all what one would have ventured to predict. In general, from the start the weight increases rapidly and then more slowly. A second spurt is succeeded by a second slowing down, and this continues. There are variations in the form which these stages assume. The rate of absorption may remain constant for a period. The essential feature is that the process consists of a series of steps. The authors have been able to fit equations to these. Of course they sought for possible causes for the discontinuities they found. Changes of barometric pressure, of temperature and of humidity, were ruled out by evidence. "The most convincing proof that the observed breaches of continuity were not due to external conditions, but intrinsic, is found in the fact that, of four samples under observation at one time and behaving similarly, one only will suddenly change its velocity of hydration, to be followed, perhaps, after an interval by a change in velocity of one of the others, the remaining two continuing their course." Flax and cotton fibres, isinglass, copper and calcium sulphate are alike in their general behavior. Copper sulphate absorbs water less rapidly from air at 100 per cent. relative humidity than from air at 87 per cent. Whether the dehydrated salts are in the form of powder or in a hard cake is without effect upon the progress of absorption. These textile investigators have brought to light a group of very interesting facts.

G. F. S.

SOME OPTICAL PROPERTIES OF FLUORESCENT RHODAMIN B.*

BY

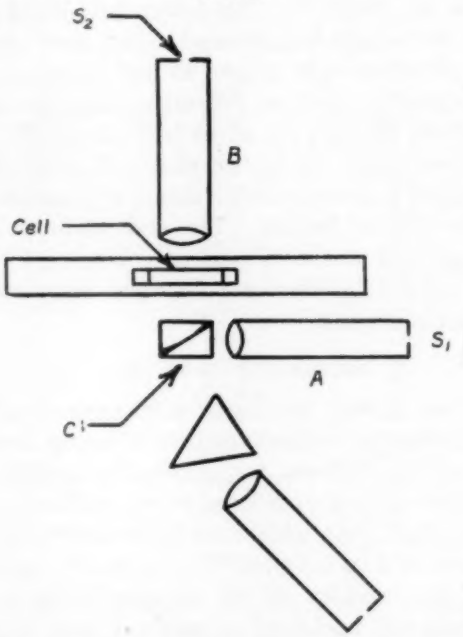
A. PORITSKY.

National Lamp Works of the General Electric Company, Cleveland.

THE purpose of the present paper was to study:

1. The absorption coefficient of rhodamin B solutions as a function of thickness and concentration.

FIG. 1.



2. The dependence of fluorescence upon previous exposure to heat and light.

3. The metallic reflection of a film of rhodamin as a function of wave-length.

A contrast Lummer-Brodhun spectrophotometer was used in the present study. The same source of light was used to illuminate the comparison field and cells containing the solutions.

* Communicated by Dr. Enoch Karrer.

The observations were carried on in a dark room. By means of suitable screens the light was prevented from striking any part of the spectrophotometer except the slits. The cells containing the pure alcohol and the solutions were placed in succession in front of the Lummer-Brodhun cube (C, Fig. 1), the collimator arm B being shifted for this purpose about $2\frac{1}{2}$ inches along its horizontal axis, thus placing the cells in the path of a parallel beam of light, and so removing the error due to the apparent change of the distance of the light source. This arrangement requires that the cell walls be strictly parallel and that the cells be perpendicular to the beam of light. To secure the latter a cell was placed in the track T. The lower half of the slit S_2 was illuminated and the light was allowed to fall upon the cell. When the cell was placed at right angles to the direction of the beam, the light retraced its path on reflection, and the reflected light could be observed through the upper half of the slit.

The cells were made up of two plates of pyrex glass, between which was placed a glass cylinder about $1\frac{1}{4}$ inches in diameter, ground to the desired height. The end surfaces of the plates were always parallel to within .001 cm. For very thin cell rings made out of celluloid plates were found to serve well. The end plates were not cemented.

RELIABILITY OF METHOD.

Since we are dealing here with a fluorescent substance there is a possibility that the ordinary method of using a source of light with a continuous spectrum for absorption studies may not be correct. Suppose we are to determine the coefficient of absorption at some wave-length lying within the fluorescent band. If a monochromatic beam of that wave-length is passed through the solution the ratio of the intensity of the incident light to that of the transmitted light will be found to have a definite value depending upon λ. If, leaving other conditions unchanged, we replace the monochromatic light by a continuous spectrum light and again determine the ratio of the intensity of the transmitted to that of the incident beam, we may expect to get a larger value for the ratio in the second case, for there will be added to the unabsorbed light of the given wave-length the fluorescent light of the same wave-length excited by the incident beam. Since the fluorescent band always appears in its totality irrespective of the wave-length

of the exciting light,[1] it would be natural to expect more intense fluorescence with a continuous spectrum source. If the effect is at all measurable, we ought to expect that the results obtained for the coefficients of absorption for a given concentration and wave-length will be different, depending whether the light is monochromatic or not.

For observations on the transmission of monochromatic light, a spectroscope was used as a monochromatic illuminator in series

TABLE I.

	λ	Coefficient of absorption for dispersed light.	Coefficient of absorption for undispersed light.
Rhodamin—water	5100		.32
	5260	.40	.41
	5450	.79	.74
	5660	.52	.48
	5900	.01	.01
Rhodamin—alcohol	5100	.34	.34
	5260	.46	.46
	5450	.95	.90
	5535	1.02	1.01
	5660	.55	.55
Rhodamin—alcohol	5100	.16	.17
	5260	.24	.235
	5450	.52	.48
	5535	.55	.54
	5660	.25	.29
	5900	.04	.03
Fluorescein—alcohol	4955	.70	.705
	5100	.32	.33
	5175	.14	.14
	5260	.04	.04

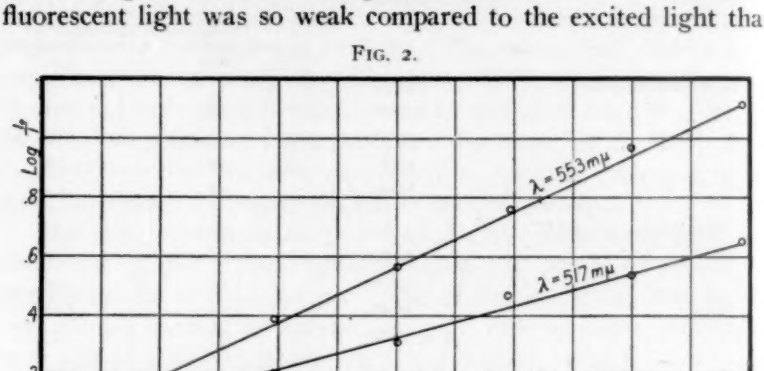
with the spectrophotometer. The light was focused upon the slit of the monochromatic illuminator by means of a concave mirror. The spectrophotometer was placed with its slit S_2 in the focal plane of the spectrum formed by the spectroscope. The latter was fixed rigidly, the spectrophotometer, however, could be shifted horizontally. The slit S_2 was kept very narrow and constant throughout the observation. The width of slit S_1, which received light after diffuse reflection from the block of magnesium carbonate, was varied to get photometric balance. From 8 to 10

[1] *Phys. Rev.*, **18**, p. 403.

balances were made for every determination. The correction for the diffraction effect, as determined by Professors Nichols and Merritt [2] for this type of instrument, was applied.

Determinations of the coefficient of absorption at various wave-lengths were made when the cells were illuminated both with dispersed and undispersed light. The solutions were rhodamin in water and in alcohol and fluorescein in alcohol. Results are given in Table I. In no case could a difference be observed that was greater than the experimental error. The additional fluorescent light was so weak compared to the excited light that its effect could not be detected by the method of observations used. Therefore undispersed light was used in all absorption observations.

FIG. 2.



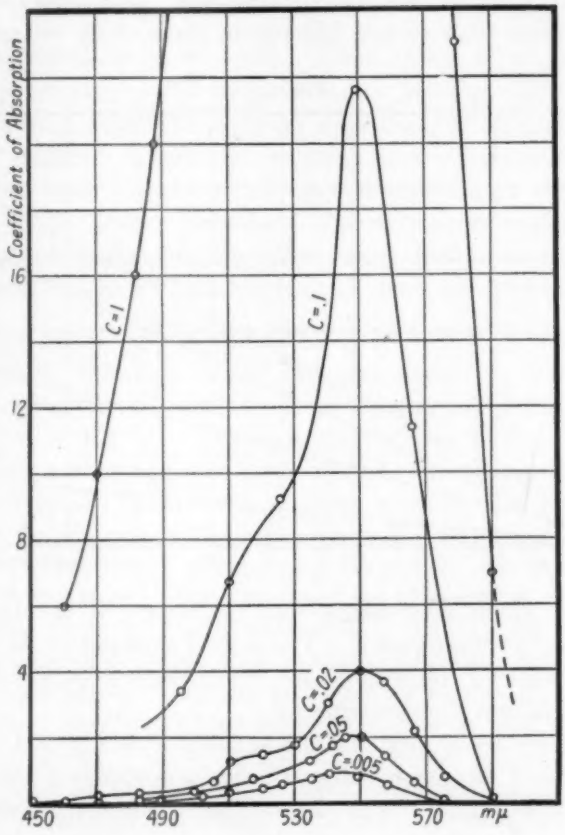
TEST OF THE EXPONENTIAL LAWS OF ABSORPTION.

(*a*) *Lambert's Law.*—It was desired to find out whether rhodamin obeys the exponential law of absorption. According to Lambert's law $I = I_0 e^{-\alpha x}$, I being the light passing after being absorbed through a layer of thickness x, and I_0 being the same light before absorption. When $\log_{10} \frac{I_0}{I}$ is plotted against X, we get a straight line through the origin if Lambert's law is obeyed. The slope of the line is equal to the coefficient of absorption. The results given in Fig. 2 show that Lambert's law is strictly obeyed by the rhodamin solutions within the observed range.

[2] *Phys. Rev.*, **21**, p. 500.

(*b*) *Beer's Law.*—Measurements were then made throughout the absorption band for solutions of various concentrations. The most concentrated solution was .1 gr. in 100 c.c. of alcohol, the least concentrated 1/200 of the above. For the most concentrated solution the cell of thickness .0265 cm. was used, but even

FIG. 3.

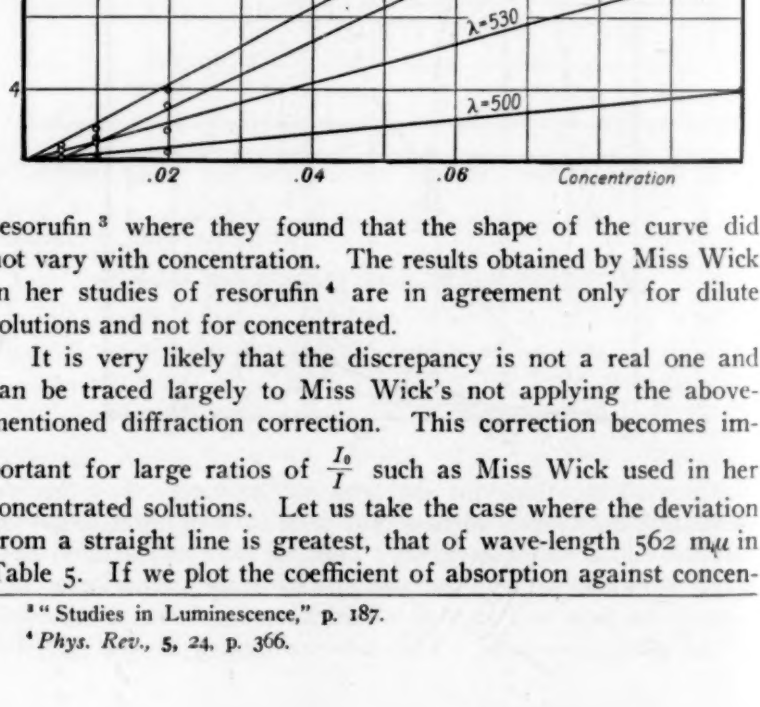


that proved too thick for the peak of the band. For the less concentrated solutions various cells were used in order to get the best conditions for observation. Thus for the concentration 1/50 a cell of thickness .239 cm. was used for the part of the band around the peak and another of thickness .796 cm. for the rest of the absorption band. The data are plotted in Fig. 3. The

curves have the same general shape that suggests that the band is a complex one having maxima at about 550 mμ and 520 mμ.

The variation of the coefficient of absorption with concentration is plotted for a few wave-lengths in Fig. 4. The points were found to lie very nearly on a straight line. This shows that there is a direct proportionality between the concentration and absorption. The results are in agreement with those obtained by Professors Nichols and Merritt in their study on eosin and

FIG. 4.



resorufin [3] where they found that the shape of the curve did not vary with concentration. The results obtained by Miss Wick in her studies of resorufin [4] are in agreement only for dilute solutions and not for concentrated.

It is very likely that the discrepancy is not a real one and can be traced largely to Miss Wick's not applying the above-mentioned diffraction correction. This correction becomes important for large ratios of $\frac{I_0}{I}$ such as Miss Wick used in her concentrated solutions. Let us take the case where the deviation from a straight line is greatest, that of wave-length 562 mμ in Table 5. If we plot the coefficient of absorption against concen-

[3] "Studies in Luminescence," p. 187.

[4] *Phys. Rev.*, 5, 24, p. 366.

tration for wave-length 562, we find that a deviation from a straight line begins with concentration ¼. From the data $\alpha = 3.175$. The cell used had an internal thickness 1.075 cm. since $\alpha x = \log \frac{I_0}{I} = 3.175 \times 1.075 = 3.4$. Antilog of $3.4 = 30$. That means in Miss Wick's data $\frac{I_0}{I} = 30$. To bring the point on the line the value of the coefficient should be 4. For the next point, with concentration $\frac{1}{2}$, $\frac{I_0}{I} = 110$. These ratios of slit widths are too large to assume the proportionality between slit width and intensity even after the ordinary correction is applied for narrow slit widths. Under the circumstances a thinner cell should have been used. A correction applied would tend to bring the point up in the proper direction. Taking another case where the values of the coefficients are rather small, that of $\lambda = 48$, we find the proportionality extends through all the concentrations studied.

FLUORESCENCE AND CONCENTRATION.

To study fluorescence the cell was placed in front of the slit of the spectrophotometer at a distance of about 4 inches (as shown in Fig. 5). Between the cell and a little to the left of the slit a mercury lamp was placed. It was enclosed in a metallic tubular jacket with a small window 2×3 cm. right opposite the cathode of the lamp, where the brightness was most intense. This window was directed toward the cell, thus exciting strong fluorescence. The lamp was so placed that no reflected light could enter the spectrophotometer. Stray light was eliminated by having the room dark and by setting black velvet screens at the proper places. Thus the most intense fluorescent light could be observed directly without allowing it first to pass through an absorbing layer. On the comparison side was placed a tungsten ribbon lamp; the ribbon was focused upon the slit of the spectrophotometer so that the image more than covered the slit. The two lamps were fed from a 44-volt battery. The current through the mercury lamp was pushed to the limit in order to obtain as high an intensity as was possible. The comparison lamp had to be kept at a rather low intensity.

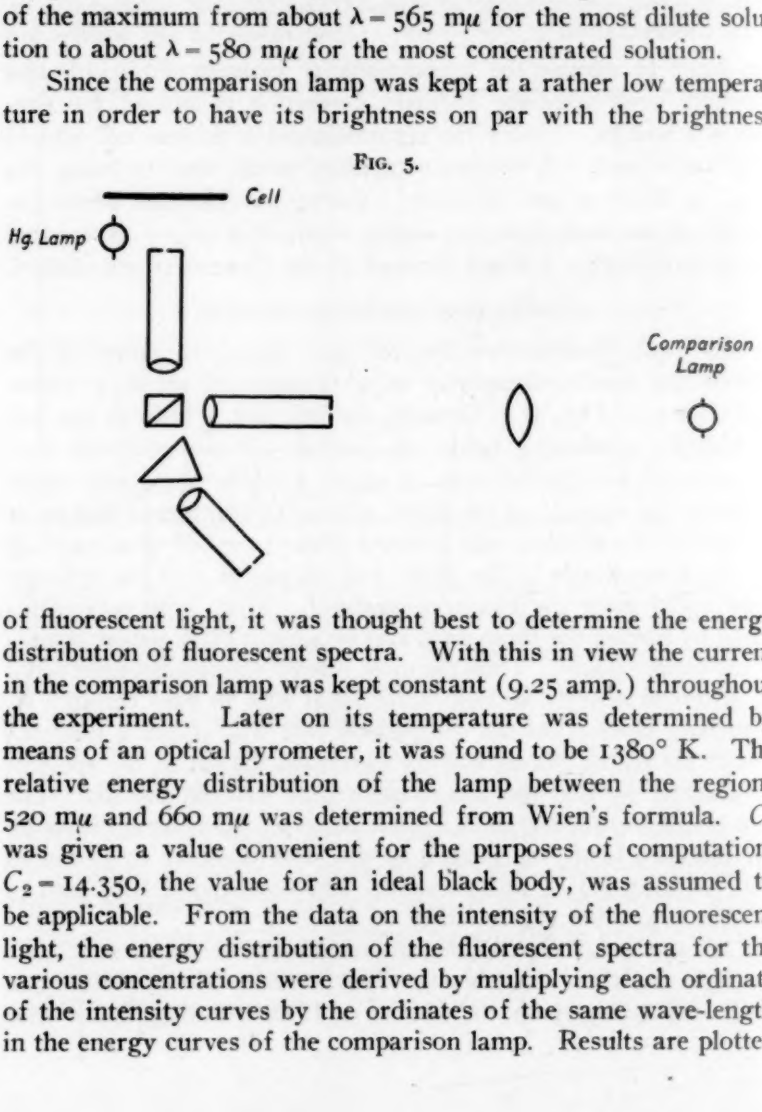
All the three slits of the spectrophotometer were 0.25 mm. through the whole experiment. The intensity of the comparison lamp was changed by the use of a Hyde rotating sector disc

previously calibrated. The current through the lamps was often checked by means of a Wölf potentiometer.

Three sets of observations were carried through on three different days on each of the concentrations, whose range was 1 to 10,000. The most concentrated solution was 1×10^{-2} gr. per c.c. and each succeeding one was .1 of the concentration of the previous one. The results of the observations show a shift of the maximum from about $\lambda = 565$ mμ for the most dilute solution to about $\lambda = 580$ mμ for the most concentrated solution.

Since the comparison lamp was kept at a rather low temperature in order to have its brightness on par with the brightness

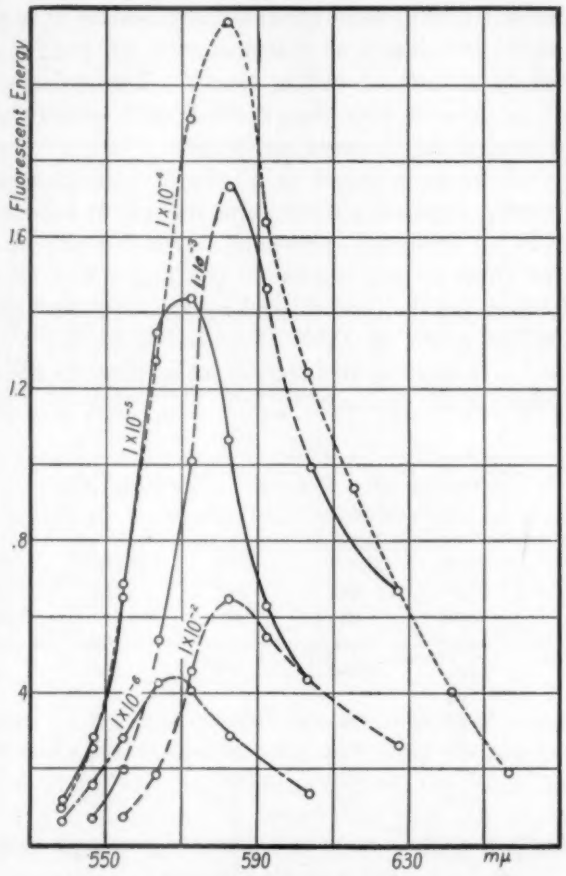
FIG. 5.



of fluorescent light, it was thought best to determine the energy distribution of fluorescent spectra. With this in view the current in the comparison lamp was kept constant (9.25 amp.) throughout the experiment. Later on its temperature was determined by means of an optical pyrometer, it was found to be 1380° K. The relative energy distribution of the lamp between the regions 520 mμ and 660 mμ was determined from Wien's formula. C_1 was given a value convenient for the purposes of computation. $C_2 = 14.350$, the value for an ideal black body, was assumed to be applicable. From the data on the intensity of the fluorescent light, the energy distribution of the fluorescent spectra for the various concentrations were derived by multiplying each ordinate of the intensity curves by the ordinates of the same wave-length in the energy curves of the comparison lamp. Results are plotted

in Fig. 6. It is of interest to notice that there is a gradual shift of the maximum of the energy distribution from wave-length $\lambda = 568$ mμ for concentration 1×10^{-6} gr. per c.c. to wave-length $\lambda = 583$ mμ for concentration 10^{-4} gr. per c.c., after which there

FIG. 6.



is no further shift even up to 10^{-2}. A possible explanation of the cause of the shift is suggested by Prof. R. W. Wood.[5]

FLUORESCENCE AFTER EXPOSURE TO HEAT AND LIGHT.

Next the effect upon fluorescence of previous exposures of rhodamin to light and heat was studied. A sample of rhodamin concentration 1×10^{-4} gr. per c.c. was divided into five equal

[5] R. W. Wood, *Phil. Mag.*, April, 1922, p. 759.

parts. One was kept as a check, another was placed near a mercury quartz lamp and was exposed to its effect for about five hours. Upon the third was focused a 400-watt lamp by means of a six-inch lens, for the same length of time. Upon the fourth a very powerful concentrated sunbeam coming from a two-foot parabolic mirror was focused for about two hours. The fifth was kept for about two hours at a temperature of 100° C., having been placed in a bath of boiling water. The solution having evaporated to dryness was then refilled with exactly the same amount of alcohol that it contained before.

After this the fluorescence of all the five samples was measured spectrophotometrically in the same manner as before. It was found that in all cases the maximum of the fluorescent intensity shifted over from $\lambda = 573$ mμ to $\lambda = 564$ mμ, which corresponds to the maximum for the most diluted solution, 1×10^{-6} gr. per c.c. The results are given in Table II and confirm R. W. Wood's observation.[6] It appears that there is an increase in the intensity of fluorescence after exposure.

TABLE II.

Fluorescence after Exposure to Light and Heat.
Concentration 1×10^{-4} *gr. per c.c.*

λ	Check.	Electric Lamp.	Mercury Lamp.	Sunlight.	Heat.
539	.021	.030	.045	.059	.031
547	.052	.089	.091	.106	.080
555	.091	.164	.172	.186	.141
564	.142	.250	.288	.248	.210
568	.154				
573	.174	.210	.246	.238	.195
583	.136	.134	.186	.141	.121
593	.071	.069	.077	.080	.058
604	.040	.039	.040	.041	.040

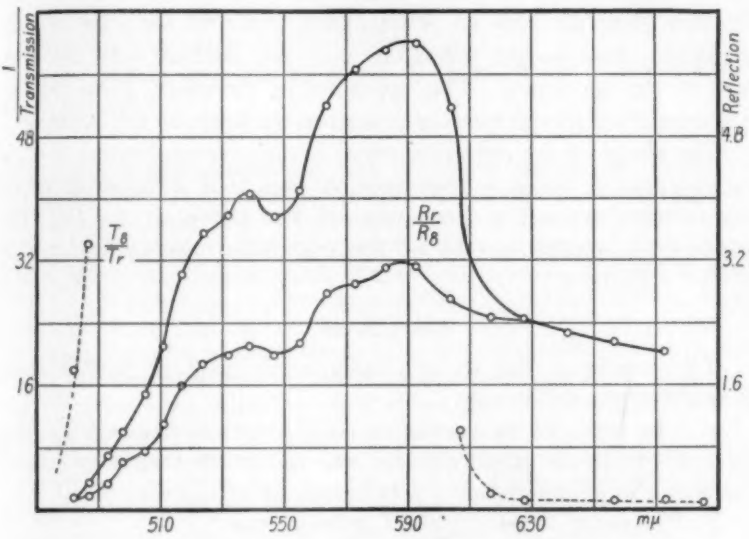
REFLECTION FROM A FILM OF RHODAMIN SOLUTION SPREAD OVER A GLASS SURFACE.

When a drop of concentrated solution (10^{-2} gr./c.c.) was allowed to evaporate upon a glass plate, it acquires a shiny non-fluorescent surface, appearing yellow by reflected light and cherry color by transmitted light. The nature of the reflected and transmitted light was then investigated by means of the spectropho-

[6] *Phil. Mag.*, April, 1922.

tometer. For studies on reflection the glass with the rhodamin film and another one just like it but without a film were placed in a stand with a device so constructed that first one and then the second piece of glass could be brought in front of the slit of the spectrophotometer. Light from an electric lamp was made to fall upon a ground-glass screen, from there upon the glass in question, and from it was regularly reflected into the spectro-

FIG. 7.



photometer. The intensity of the reflected light coming from glass rhodamin was compared with that from the glass alone.

Then a study of the transmission of the same two pieces of glass was undertaken. It was found that the rhodamin film had a very strong and sharp absorbing band beginning with $\lambda = 485$ mμ and extending to $\lambda = 605$ mμ (in which respect it behaved like the rhodamin solution); so great, however, was the absorption that with all the lamps which have been tried, not a trace of light was transmitted within the absorption band.

The results obtained on reflection and transmission are plotted in Fig. 7. The dotted lines represent the transmission of that part of the spectrum within which observations could be made.

The ordinates represent the ratio $\frac{T_g}{T_r}$, transmission through clear glass to the transmission through the glass rhodamin. The solid curve represents $\frac{R_r}{R_g}$ or the ratio of intensities of light reflected from the rhodamin glass surface and clear glass. The lower full-line curve gives the observed values. The upper curve is obtained by multiplying the ordinates of the lower curve between $\lambda = 487$ mμ and $\lambda = 605$ mμ by the factor 1.92[7] to reduce the reflection from the two glass surfaces to one surface, since in the case of the rhodamin glass we get reflection from one surface only for that part of the spectrum. The upper curve therefore gives nearer approximation to the relative reflection throughout the spectrum.

The shape of the reflection curve is rather complicated, and in the absence of complete transmission data it is difficult to draw any conclusions. The minimum of the curve at $\lambda = 547$ mμ corresponds approximately to the maximum absorption in the alcohol solutions.

CONCLUSION.

The results of the above investigation upon rhodamin seem to establish the following:

1. The value of the coefficient of absorption obtained for any wave-length is the same whether the transmitted light is monochromatic or comes from a continuous spectrum source.

2. Rhodamin strictly obeys Lambert's law.

3. There is a direct proportionality between concentration and absorption within the observed limits.

4. The maximum of the energy distribution of the fluorescent band shifted with increase in concentration from $\lambda = 567$ mμ to $\lambda = 583$ mμ, further increase in concentration has no effect.

[7] The factor 1.92 was obtained in the following fashion: Let I be the intensity of the incident light and r the fraction reflected, then Ir is reflected from the first surface and $Ir\ (1-r)$ from the second surface, part of which will be lost by reflection from the first surface. The light coming from the two reflections will be $Ir + Ir(1-r)^2 = A$. Since we are interested in the light coming from the first surface only or Ir, we solve for $Ir = \frac{A}{1+(1-r)^2}$. The light from the rhodamin glass surface is $Ir_1 = B$; $\frac{Ir_1}{Ir} = \frac{B\,(2-2r+r^2)}{A}$ putting $r = .04$ (approximately) and neglecting r^2 in comparison with r we get $2 - 2r = 1.92$.

5. Subjecting a rhodamin solution to heat and to intense light caused a shift of the maximum of the fluorescent intensity from 573 mμ towards 564 mμ.

6. The absorption band of a dry rhodamin film is located in the same part of the spectrum as the solution from which it comes, but unlike the solution it possesses an intense metallic reflection.

The work described in this paper was begun at Ithaca and completed in the Research Laboratories of the National Lamp Works of the General Electric Company as a part requirement for the degree M.S. at Cornell University.

My thanks are due to Prof. E. Merritt for his encouragement and aid.

Some Experiments on the Proportionality of Mass and Weight. H. H. POTTER. (*Proc. Royal Soc.*, A 728.)—"The earliest experiments on this subject were carried out by Newton, who came to the conclusion that the gravitational accelerations of gold, silver, lead, glass, sand, common salt, wood, water and wheat were equal to within one part in a thousand. In 1827 similar experiments were carried out by Bessel. His method was to suspend his pendulum bob from two threads of different length and to measure the period in each case by comparison with a standard clock. His experiments were carried out with great care, and Bessel came to the conclusion that, with one possible exception—the case of water—the gravitational acceleration was the same for all substances which he tried to one part in 60,000. Prof. O. W. Richardson has suggested a theory which might lead one to suspect some such variation for water and for several other light elements and compounds.

"The mass of an atom is due almost entirely to its nucleus, and it is highly probable that the nuclei of all elements are formed by the close union of either hydrogen or helium nuclei or both. Experiments in radio-activity have shown beyond all doubt the presence of helium in the nuclei of the elements of high atomic weight, and Rutherford has apparently been successful in driving hydrogen out of the nitrogen atom. It is most probable, at any rate, that we have not more than two fundamental positive ions—the nuclei of hydrogen and helium. Professor Richardson suggests that there may be a slight difference in the gravitational constants of the helium and the hydrogen nuclei; the reason why no such difference has never been found lying in the fact that nearly all substances for which 'g' has been measured have been substances which might reasonably be expected to consist almost entirely of helium." Of the substances used by Bessel, water is the only one that could have a considerable hydrogen content, and it was in the case of water that Bessel's result

was anomalous. "The method used in these experiments was very similar to that adopted by Bessel, except that some simplifications have been introduced on account of the fact that no attempt has been made to measure the absolute value of gravitational accelerations, a comparison only of the accelerations being attempted. The principle of the experiment has been to compare the period of the experimental pendulum with that of a standard invar pendulum, by means of the method of coincidences." Lead, steel, ammonium fluoride, bismuth, paraffin wax, mahogany and duralumin were investigated. "If we neglect the case of steel, the greatest deviation in the period of any pendulum from the period of the corresponding brass pendulum was only one part in 300,000, a deviation which is not bigger than possible experimental error. It is somewhat striking that the three substances, ammonium fluoride, paraffin wax and mahogany, which are 'rich in hydrogen' appear to have a slightly greater gravitational acceleration than do the other substances." The conclusion is reached that all the substances have the same acceleration within the limits of errors of experiment.

Experiments showed that brass and bismuth have the same acceleration. The same equality was found for brass and duralumin, 95 per cent. aluminum. These seem not to be in accord with the results of C. F. Brush, who finds the gravitational constant of aluminum to be about twice that of bismuth. In his pendulum experiments Brush detects a difference between substances which should certainly have come to light in the present research, were it real. "Brush appears to have ignored the buoyancy correction in his pendulum experiments. Using 1.84 as the buoyancy factor, the correction which he should have applied comes out of the right order to explain his anomalous results." G. F. S.

The Determination of Avogadro's Number from Observation on Bacteria (Cocci). J. H. SHAXBY. (*Proc. Royal Soc.*, A 728.)—In the Brownian movements of particles in a fluid there is a simple equation linking together the displacement in any chosen direction experienced by the particle in a given time, the viscosity of the medium, N (the number of molecules in a gram-molecule of a perfect gas) and the radius of the particles. N, which is Avogadro's number, was found to be equal to about 6.8×10^{23} by Perrin, who dealt with liquid suspensions, while Fletcher and Eyring, using gases, arrived at the number, 6.06×10^{23}. There is no small difference between these two results. The discrepancy may be due to the electric charge of the particles. To test this it seemed wise to make the determination with particles widely different from those of gamboge used by Perrin. Both *Staphylococcus aureus* and *Staphylococcus albus* were employed. The cocci were wetted by water and thus obviated the electrical difficulty. "The weighted mean of the measurements with *Staphylococcus aureus* is 6.22×10^{23}, that from *Staphylococcus albus*, 6.08×10^{23}." G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

STANDARDIZATION OF HOSIERY BOX DIMENSIONS.[1]

By Charles W. Schoffstall and E. M. Schenke.

[ABSTRACT.]

HOSIERY boxes in use at the present time are represented by photographs and a series of graphs which show the waste, defects in packing, breakage, etc. A list of dimensions is given as proposed standard dimensions of hosiery boxes for men's, ladies', and children's hosiery. It is estimated that a reduction of 76 to 83 per cent. of the present sizes will result from the adoption of these standards. A new method of packing men's hosiery is shown, which will make a more presentable package and result in an additional saving of space. The results to be obtained from the standard hosiery boxes are discussed along the lines of waste materials, storage space, smaller shipping cases, cost of boxes, reduction of crushing, and breakage of boxes.

LEGAL WEIGHTS (IN POUNDS) PER BUSHEL OF VARIOUS COMMODITIES.[2]

[ABSTRACT.]

THIS circular shows the weights per bushel of various commodities, as fixed by national legislation for customs purposes, or by State legislation for the purpose of commerce within the State. Weights are given for about 165 commodities. The tables show wide differences in the weights of some commodities. In others more general agreement is had, and in a few, complete uniformity obtains. There is a greater degree of uniformity in the weights of commodities at the present time than was formerly the case, and it may also be said that a larger number of States have discarded bushel weights and now require commodities to be sold by weight or numerical count. The circular contains also an account of the Winchester bushel, setting forth the manner in

* Communicated by the Director.

[1] Technologic Papers, No. 253, price ten cents.

[2] Circular No. 10, price five cents.

which it came to be recognized as the customary standard of the United States, the legal status of this measure, and its accepted dimensions. A short résumé is given of what is deemed to be the proper interpretations to be placed upon the State laws establishing weights per bushel, and a table has been included in the present edition giving an analysis of the degree of uniformity in weight existing in the cases of those commodities for which bushel weights have been generally established.

SPECIFICATION FOR NUMBERED COTTON DUCK FOR GOVERNMENT AND COMMERCIAL USE.[3]

[ABSTRACT.]

THE second edition of the specification for numbered cotton duck as prepared by the Cotton Duck Association, the technical committee on textiles of the Federal Specifications Board, and the Bureau of Standards under the supervision of the textile section includes, in addition to the requirements set forth in the former edition, a method for measuring length of duck. The other requirements include weave, width, weight, count, ply, and breaking strength (standard grab 1 by 1 by 3 inch method), also an expression of what constitutes a good delivery. The requirements are given for hard texture ducks from Nos. 2/0 to 12 and medium texture ducks from 2/0 to 6.

A STANDARDIZED METHOD OF MEASURING THE SIZE OF HOSIERY.[4]

[ABSTRACT.]

THE development of a standard method of measuring the size of hosiery was accomplished through a questionnaire and analysis of the replies to the questionnaire, each stating definitely the method of measuring the size and indicating the application of the ruler on the foot of the hosiery, stating the exact position. Nine different methods, each of which is shown in the paper, were found to be in use.

The various methods indicated that for any one specific hose a difference of one full size could be obtained. The selection of the standard was based on two considerations—first, that of the

[3] Circular No. 136, price five cents.
[4] Circular No. 149, price five cents.

numerical average of the nine methods, and, second, the consideration of the manufacture of the hosiery, making the line pass through the two most consistent points in the hosiery. These two points were selected to be the tip of the toe and the bottom of the heel gore. The standard method of measuring the size of hosiery consists of placing the ruler on the hose, after the hose has been boarded and pressed and appears in a flat, unwrinkled condition, along the line in which the tip of the toe and the bottom of the heel gore are connected, measuring the distance along this line from the tip of the toe to the back of the heel to the nearest half inch, giving preference to the lower number for the hosiery size.

WALL PLASTER: ITS INGREDIENTS, PREPARATION AND PROPERTIES.[8]

[ABSTRACT.]

THE art of plastering is intimately connected with the comfort and safety of the occupancy of buildings, yet few outside the trade understand the nature of the material and the details of the work required to produce the desired results. The recently aroused interest in building has carried with it interest in plastering.

Much information about the factors which enter into successful plastering was found available in the trade. This paper represents an attempt to collect and correlate this information for the public benefit.

To assist in the work, a committee known as the Bureau of Standards Plastering Conference was organized of men most familiar with the different phases of the subject. From the information thus furnished, and from laboratory research work, we have been able in many cases to explain not only how an operation is conducted but also why this is the best way of doing it.

It is recommended that furring be used when plastering exterior masonry walls, to prevent damage due to condensed moisture.

When masonry walls are to be plastered without furring, the surface of the masonry should be true and clean and of the proper degree of wetness.

Specifications and directions for erecting are given for wood, wire and metal lath, and gypsum plaster board.

[8] Circular No. 151, price fifteen cents.

Descriptions and specifications are given for the ingredients of plaster—lime, gypsum, cement, sand, hair, water, etc.

The chief properties of the wet mix are discussed, as they affect the quality of the finished plaster.

Complete directions are given for the mixing of the ingredients and the application of the wet mix to the wall.

The chief properties of the hardened plaster are discussed as they affect the comfort and safety of the occupant.

Different kinds of decorative features are described.

Some of the common defects are described, and their causes and remedies suggested.

Attention is called to the factors to be considered when selecting materials for plastering, in order that they may be best adapted to the particular case.

RECOMMENDED SPECIFICATIONS FOR QUICKLIME AND HYDRATED LIME FOR USE IN THE MANUFACTURE OF SAND-LIME BRICK.[*]

[ABSTRACT.]

THIS is the sixth of a series of specifications for the lime used in various chemical industries. To assist in the development of these specifications, the bureau has called together an Interdepartmental Conference on Chemical Lime, composed of representatives of the Geological Survey and Bureau of Mines of the Interior Department; the Bureau of Soils, Bureau of Chemistry, Forest Service, and Fixed Nitrogen Research Laboratory of the Department of Agriculture; and the Chemical Warfare Service of the War Department. The present specification, based on a draft originally prepared by W. E. Emley, of the lime section, Bureau of Standards, has been unanimously approved by the above conference and by the National Lime Association.

Either quicklime or hydrated lime may be purchased for making sand-lime brick, but the former must be completely hydrated before it can be used. Material of about 85 per cent. purity and reasonably low in magnesia is required. The lime must also be reasonably fresh, as indicated by a low content of carbon dioxide. Methods of analysis are given in detail.

[*] Circular No. 150, price five cents.

RECOMMENDED SPECIFICATION FOR CERAMIC WHITING.[1]

[ABSTRACT.]

THIS is the fifth of a series of specifications for the kinds of lime required by different chemical industries. The preceding four dealt, respectively, with lime used in cooking rags, in causticizing, and in the manufacture of sulphite pulp and glass. This deals with lime used in making glazes, enamels, and similar ceramic products. Ceramic whiting is really calcium carbonate, with or without a small amount of magnesium carbonate, but it performs the function of lime. It should contain not less than 97 per cent. of carbonates, and should be very fine, so that 98 per cent. of it will pass a No. 200 screen.

RECOMMENDED SPECIFICATION FOR QUICKLIME AND HYDRATED LIME FOR THE MANUFACTURE OF SILICA BRICK.[2]

[ABSTRACT.]

A BRIEF description of the way in which lime is used in the manufacture of silica brick is followed by a general statement as to the quality of lime required.

The standard of quality is set at 92 per cent., based on the nonvolatile matter, with maximum limits of 5 and 10 per cent. carbon dioxide, depending upon whether the sample is taken at point of shipment or of destination.

Complete directions for sampling and testing are included.

SIMPLIFIED PRACTICE RECOMMENDATION NO. 4—ASPHALT.[3]

[ABSTRACT.]

HIGHWAY engineers are insisting upon too great refinement in their specifications for asphalt for road work. A review of the requirements of a number of State highway departments indicates wide variations in the most important test for asphalt quality, namely, penetration. It is true that for certain special conditions

[1] Circular No. 152, price five cents.
[2] Circular No. 153, price five cents.
[3] Simplified Practice Recommendation No. 4.

of traffic or climate special grades of asphalt may be necessary, but according to the views of asphalt-producing interests, there is opportunity for constructive work in eliminating the number of asphalt varieties called for without lowering the quality of any of the types of construction in which asphalt is used.

It is maintained that, for all practical purposes, an upper limit of seven grades of material is ample as against thirty or more which are now demanded in the specifications which highway engineers have issued in the various States. The plea for fewer grades of asphalt comes from the producer. The chemistry of asphalt and tests to determine its quality constitute a highly technical problem that is understood by a comparatively small group of specialists. Highway and paving officials, without a full realization of the manufacturing problems involved, have been in the habit of basing their specifications on those used elsewhere for similar work, injecting special requirements here and there to secure some supposedly special advantage in the product for their own work. The result has been the production of scores of specifications without correlation and with variations in demands which, the producers feel, while accomplishing no real good, hamper operations at the refineries.

The division of simplified practice of the Department of Commerce was requested to coöperate with the producers with a view of adopting certain recognized penetration limits that would ably meet all requirements. On April 24th the manufacturers met in response to an invitation from the department to discuss the plans and procedure necessary to bring about a general conference to reach the desired goal. This preliminary conference resulted in a survey being made showing the penetration limits now being used, and May 28, 1923, was decided upon for calling the general conference.

On May 28th a compilation of the figures submitted in response to the survey was submitted at a general conference of manufacturers, distributors, and users, including representatives of the American Association of State Highway Officials, the American Society for Testing Materials, the American Society for Municipal Improvement, and the Asphalt Association. This conference unanimously agreed upon definite penetration limits for construction of sheet asphalt, asphaltic concrete, and asphalt macadam pavements, and also for surface treatment, as follows:

25 to 30, 30 to 40, 40 to 50, 50 to 60, 60 to 70, 85 to 100, 100 to 120, 120 to 150, 150 to 200; for joint filler for various types of construction: 30 to 50, 50 to 60, 60 to 70, 85 to 100.

The first is used primarily for brick pavements and does not require the admixture of sand, whereas the latter three, which are identical with three of the grades adopted for asphalt pavement construction, are those which would ordinarily be used in admixture with sand to produce an asphalt grout.

In adopting these limits, it is understood that the producer will furnish asphalts with penetration equal to the midpoint in each range, a plus and minus tolerance from that midpoint being acceptable to all parties, but in no case shall the deviation exceed the limits of the grade specified.

This recommendation is to become effective on all deliveries of material after January 1, 1924.

ANNUAL REPORT OF THE DIRECTOR OF THE BUREAU OF STANDARDS, 1922–23.[10]

[ABSTRACT.]

THE activities of the Bureau of Standards during the past fiscal year have been largely along lines similar to those described in the report for the preceding year. The close coöperation with industrial groups has continued with very satisfactory results. This is brought out by the number of members of the staff who have served on advisory committees of the industries, often as chairmen of the committee, and by the nineteen research associates sent to the bureau for work on special problems by industrial associations and manufacturers. The director of the bureau is the president of several technical societies, the Annual Conference on Weights and Measures, chairman of the Federal Specifications Board, and of the National Screw Thread Commission, and himself serves on many of these committees.

Several important changes have been made in the arrangement of the report.

The first portion deals with the functions and organization of the bureau, and its relations to the Federal, State, and municipal governments; the industries; and the public. An organization chart of the bureau's divisions and sections and brief statements

[10] Miscellaneous Publications, No. 53.

covering the more important lines of work carried out during the year are included.

This introductory section is followed by the detailed reports of the eleven scientific and technical divisions, the office, and the operation and construction divisions. In the case of the scientific and technical divisions each report is preceded by a work chart giving the status of all tests and investigations on June 30, 1923, and some general statistics covering the divisions, expenditures, personnel, publications issued, etc. The names of division and section chiefs and those in charge of each investigation are included in the report.

The detailed reports of the divisions are followed by some brief recommendations of the director to the Secretary of Commerce concerning the bureau's work during the coming year. The bureau's personnel during the year numbered 896. In the various laboratories 127,000 tests were carried out, and ninety-one new publications were issued. The total funds received during the year totaled $1,719,156.92.

On December 31, 1922, Dr. S. W. Stratton, director of the bureau since its establishment in 1901, resigned to accept the presidency of Massachusetts Institute of Technology. He was succeeded by Dr. George K. Burgess, for some years chief of the metallurgical division.

APPLICATION OF THE INTERFEROMETER TO MEASUREMENTS OF THE THERMAL DILATATION OF CERAMIC MATERIALS.[11]

By George E. Merritt.

[ABSTRACT.]

IN this paper an interference method and apparatus for measuring the thermal expansion of ceramic materials are described. The samples in the form of small pins, 0.5 to 10.0 mm. in length, are placed between two fused quartz interferometer plates and heated in an electric furnace. The elongation of the samples is determined from the numbers of interference fringes that pass reference marks on the interferometer plate while the sample is being heated. A change in length of the sample of 0.025μ, or one-millionth of an inch, can be easily detected. In order to show

[11] Scientific Papers, No. 485, price five cents.

the application of this method to the study of the expansion of ceramic materials, measurements were made on several samples of glaze, terra cotta, tile, porcelain, and clay in the temperature interval 20° to 1000° C. Some of the samples were especially prepared, while others were taken from finished products, some of which had failed in service.

The results of the measurements show that the expansivities of different ceramic materials may differ greatly; therefore when two or more materials are combined, as in the case of glaze on tile or terra cotta, the difference in expansion of the parts may cause the glaze to crack or scale off. It was also found that a material might undergo permanent dimensional changes when subjected to heat treatment, and that its expansivity, though reproducible, might be very different at different parts of the temperature scale. If such a material is cooled quickly or subjected to sudden temperature changes, either cracking may occur or merely strains be set up which cause subsequent failure. These facts emphasize the need for information on the expansivity which the method is capable of giving.

SIMPLIFIED PRACTICE RECOMMENDATION NO. 10—MILK AND CREAM BOTTLES AND BOTTLE CAPS.[12]

[ABSTRACT.]

REPRESENTATIVES of the International Milk Dealers Association, the Glass Container Association, the Cap Manufacturers Credit Association, and the National Association of Bottle Manufacturers met in a general conference at the Department of Commerce on April 26, 1923, to determine upon recognized sizes of milk bottles and milk bottle openings. The conference unanimously recommended three sizes of milk bottles for quarts, pints, and half-pints, respectively, with one size opening for the entire group. Before this constructive step milk bottles were manufactured in twelve sizes for quarts; thirteen sizes for pints; fourteen sizes for half-pints; ten sizes for quarter-pints; and approximately ten sizes of caps were required to fit this varied assortment. The results of this conference are published in detail in the "Waste Elimination Series" of the Department of Conference and will be known as Simplified Practice Recommendation No. 10.

[12] Simplified Practice Recommendation No. 10, price five cents.

INVESTIGATIONS ON THE PLATINUM METALS, IV, THE DETERMINATION OF IRIDIUM IN PLATINUM ALLOYS BY THE METHOD OF FUSION WITH LEAD.[19]

By Raleigh Gilchrist.

[ABSTRACT.]

A STUDY has been made of the analytical details of the Deville and Stas method for the determination of iridium in platinum alloys containing from 0.1 to 20 per cent. of iridium. Specially prepared alloys, made from highly purified metals, were used in the investigation. It was found that the concentration of aqua regia, the proportion of lead, and the time and the temperature of the lead fusion can be varied over a wide range without affecting the determination. The observations of Deville and Stas that palladium and rhodium have no effect upon the determination and that ruthenium separates quantitatively with the iridium were confirmed. In addition, gold was found not to interfere. Iron separates nearly quantitatively with the iridium, as observed by Deville and Stas. A method for the separation of iron from the iridium was tested and found to give satisfactory results. The loss in weight of crystalline iridium during the ignition periods is insignificant and the weight of crystalline iridium is not affected by heating and cooling in an atmosphere of hydrogen. Spectrographic examination of samples of iridium from analysis showed that neither platinum nor lead was present in sufficient quantities to affect the determination.

The following modified procedure, combining the optimum conditions for speed and accuracy in the various details of manipulation, is offered:

Fuse the carefully sampled platinum alloy with ten times its weight of granular test lead for one hour at about 1000° C. A covered crucible, whose outside dimensions are 1½ inches in diameter and 2½ inches in height, machined from Acheson graphite, is suitable for fusions using 20 to 40 grams of lead. The inside of the crucible should possess a slight taper to facilitate the removal of the cooled ingot. Do not pour the fusion from the crucible, but allow it to solidify, since the iridium has largely settled to the bottom of the crucible. The crucible is best heated in an electric furnace.

[19] Scientific Papers, No. 483, price five cents.

Brush the cooled lead ingot free from carbon, place it in a beaker, and add one volume of nitric acid (specific gravity 1.42) to four volumes of water, using 1 c.c. acid per gram of lead. Maintain the temperature of the solution at about 85° C. (steam bath), under which condition the disintegration is usually complete in two hours. Dilute the solution with water to twice its volume, and decant it through a double filter, consisting of a 9-cm. paper of fine texture, such as S. & S. No. 589 blue ribbon filter, on which is superimposed a 7-cm. paper of looser texture, such as No. 589 black ribbon. Wash the residue by decantation with hot water and return the wet filters to the beaker.

Add in order 15 c.c. of water, 5 c.c. of hydrochloric acid (specific gravity 1.18) and 0.8 c.c. of nitric acid (specific gravity 1.42) for each gram of platinum alloy sample taken. Heat the solution at about 85° C. until the lead-platinum alloy is completely dissolved. One and one-half hours usually is sufficient. Dilute the solution with twice its volume of water and transfer to a double filter, first, the macerated paper and then the iridium. Wipe the inside of the beaker with a piece of moist filter paper to collect any adhering iridium. It is well to whirl a small quantity of water in the beaker, the action of which collects any remaining iridium in one place, whence it can be removed with a piece of paper. Whirling of the lead nitrate solution, from the first filtration, and of the chloroplatinic acid solution aids in the detection of any particles of metal which may have escaped the filters by causing them to collect at the centre of the bottom of the receiving flask. Wash the contents of the filters, first with hot water, then with hot dilute hydrochloric acid, and lastly with hot water.

Dry the filtered mass in a porcelain crucible, ignite it thoroughly in the air, reduce it in hydrogen, and weigh as metallic iridium.

Correction for small amounts of ruthenium, if desired, can be made according to the original instructions of Deville and Stas. Correction for iron may be made by deducting the percentage of iron found in the filtered solutions from that determined in a separate sample. An alternative method consists of a fusion of the iridium, obtained from analysis, with zinc, removal of the excess zinc with hydrochloric acid, fusion with potassium pyro-

sulphate, extraction with water, removal of silica in the regular manner, and the recovery of iridium.

EQUALIZER APPARATUS FOR TRANSVERSE TESTS OF BRICKS.[14]

By H. L. Whittemore.

[ABSTRACT.]

THE American Society for Testing Materials has described the apparatus to be used for making transverse tests of building bricks. As this apparatus is made up of many loose parts, considerable time is required to prepare the next specimen for test.

A new equalizer apparatus has been designed, built, and tested, which gives practically the same values for the modulus of rupture as the A. S. T. M. apparatus. It consists of two equal arm levers about the length of the brick, mounted side by side on a pin at the middle of their length. At each end the levers have barrel-shaped knife edges carried on vertical spring-steel plates, which allow longitudinal movement of the knife edges. The levers equalize the four forces acting upward on the lower surface of the brick. The upper knife edge and the bearing plate are self-adjusting.

The time required for testing with this new apparatus was found to be about 58 per cent. of that required if the A. S. T. M. fixture is used.

MEASUREMENT OF LOW RESISTANCES BY MEANS OF THE WHEATSTONE BRIDGE.[15]

By Frank Wenner and Alva Smith.

[ABSTRACT.]

THE paper gives a procedure that leads to a fairly high accuracy in the measurement of resistances as low as 0.01 or even 0.001 ohm with the Wheatstone bridge. It is pointed out that if a low resistance is to be definite it must have distinct current and potential terminals. An essential feature in the procedure consists in making the potential terminals of the low resistance

[14] Technologic Papers, No. 251, price ten cents.

[15] Scientific Papers, No. 481, price five cents.

two of the branch points of the bridge, to one of which a battery lead is connected and to the other of which a galvanometer lead is connected. Consequently the terminal and lead resistances to the unknown are added to the resistances of the adjacent arms. Since these arms have resistances that are high compared with the unknown, the errors introduced into a bridge measurement by these terminal resistances are small compared with those existing when the ordinary procedure with the bridge is followed. In fact, a single measurement made in this manner gives sufficient accuracy for many purposes.

However, where higher accuracy is desired it may be obtained by making two additional measurements with the same apparatus and correcting for the effect of the terminal resistances. Neither of these secondary measurements needs to be made with as high accuracy as the primary measurement, since they are made to obtain small corrections to be applied to the primary measurement. One of these secondary measurements is made with the battery lead transferred from the potential terminal of the unknown to the corresponding regular terminal of the bridge. The other of these secondary measurements is made with the battery lead in its original position on the potential terminal of the unknown, but with the galvanometer lead transferred from its position on the potential terminal of the unknown to the corresponding regular terminal of the bridge. These three measurements give three independent relations between the unknown, whose value is desired, the known resistance of the bridge arms, and two unknown connecting resistances. By an elimination of terms containing the connecting resistances an approximate solution is obtained for the value of the unknown.

The paper contains data showing the accuracy obtained in measurements of resistances of the order of 0.01 ohm and 0.001 ohm. In the measurement of a resistance of the order of 0.001 ohm an accuracy of 0.6 per cent. was obtained by the primary measurement alone and of 0.03 per cent. when corrections obtained by the secondary measurements were applied. We do not consider the accuracy obtainable by this procedure comparable with that which may be realized with a Thomson double bridge. However, we present it as a convenient procedure to be used where the highest accuracy is not required and where more suitable apparatus is not available.

THERMAL CONDUCTIVITY METHOD FOR THE ANALYSIS OF GASES.[16]

By P. E. Palmer and E. R. Weaver.

[ABSTRACT.]

OF the many physical characteristics of gases which offer possibilities for the development of gas-analysis instruments, the thermal conductivity is probably the most useful. The ability of gases to conduct heat is possessed to considerably different extents by the various gases. The wide differences afford a means for gas analysis by comparisons of the thermal conductivities of certain mixtures of gases with that of a reference gas. By making use of differences in chemical properties in addition to the differences in this physical property, the utility of the thermal conductivity method is greatly extended.

The principles governing the construction and operation of the gas-analysis apparatus, depending upon thermal conductivity developed at the Bureau of Standards, are as follows: A platinum wire of definite length is stretched along the axis of a cylindrical cell and is surrounded by a slowly flowing stream of the gas undergoing analysis. An exactly similar wire is exposed to a standard or comparison gas. The two wires are connected in series in an electrical circuit and are supplied with current from a source of constant e.m.f.

Heat is generated by the passage of the current, and the wires rise in temperature until the continuous dissipation of thermal energy is equal to the electrical energy supplied. By a proper construction of the cells, all loss of heat, except by conduction through the gases surrounding the wires, is reduced to a small proportion of the whole. In such cells the temperatures attained by the wires will depend mainly upon the thermal conductivities of the gases contained in the cells. Inasmuch as platinum has a high temperature coefficient of electrical resistance, the resistance of the wire, depending as it does on the temperature, will have a value corresponding to the thermal conductivity, and, therefore, to the composition of the gas.

For comparing the resistances of the two wires a shunted slide-wire provided with extension coils may be connected in parallel with the two wires to the source of current. One terminal of a

[16] Technologic Papers, No. 249, price twenty cents.

galvanometer is joined to the common connection between the two cells and the other terminal is connected to the contact of variable position on the slide-wire. Since the arrangement is that of a Wheatstone bridge, the position of the galvanometer connection on the slide-wire required for no deflection of the needle is a measure of the relative resistances of the wires. The resistances of the extension coils are so chosen that the position of the contact, with respect to the ends of the slide-wire, is a direct indication of the percentage of the desired constituent in the gas mixture being analyzed. When this arrangement is used, gas analysis can be recorded by an instrument which is essentially a self-balancing Wheatstone bridge. Such instruments are widely used in resistance thermometry. A pen automatically records the position of the contact on the slide-wire, thus indicating on a chart the composition of the gas.

The resistances of the wires may also be compared by means of an unbalanced Wheatstone bridge arrangement in which fixed resistance coils form two arms. These coils are adjusted so that the bridge will be balanced for only one composition of the gas for analysis. Either a recording low-reading voltmeter or potentiometer when properly calibrated affords a measure of the percentage composition of the gas mixture.

Current for the operation of the measuring circuit is usually supplied by a storage battery. Sufficient sensitivity to changes in gas composition is secured in most applications with the wires heated to less than 200° C. Although some heat is carried away by the gas stream, the rate may vary from 0 to 20 c.c. per minute without producing any change in the recorder readings from cooling the wires.

On a Null Method of Measuring the Gyro-magnetic Ratio. W. Sucksmith and L. F. Bates. (*Proc. Roy. Soc.*, A 727.)—Upon a circular horizontal platform that is free to turn about a vertical axis passing through its centre let there be distributed with something like uniformity a large number of wheels, all in rotation with their axes pointing in all directions. Suppose that in some way each wheel, still rotating, has its axis shifted until to a person looking down upon the group of machinery all the wheels are seen to have their axes vertical and to be turning in the same sense. As a result of this change the angular momentum of the aggregate has been changed and it, platform and wheels, will experience a temporary torque and will

start to turn about the axis. Were all the wheels to turn upside down, the platform would rotate in the opposite direction. Let this mechanical conception be applied to a magnet where each magnetized particle has a whirl of electricity and will act like a wheel in rotation. A cylindrical bar of iron, with its magnetic particles having their axes in all directions, is hung with its length vertical within a magnetizing coil. When a current passes through the latter it magnetizes the iron, that is, it makes the already magnetized particles arrange themselves so that their axes are in a general sense at least in the direction of the length of the rod and, further, so that they are turning in the same sense. This rearrangement of the magnetic gyrostats brings about a change in the angular momentum of the system and the rod turns about its axis. When the current reverses itself the system turns in the opposite sense. We have here mechanical rotation produced by magnetization. Richardson, in 1908, pointed out that "a change M in the magnetic moment of a specimen of such material should be accompanied by a change in the angular momentum U given by $\frac{U}{M} = \frac{2m}{e}$, where m and e are the mass and charge of an electron, respectively." The left side of this equation has been determined experimentally several times and it persists in coming out equal to just about half of the value of the right side.

In this experiment an aluminum wire rigidly connected to the iron cylinder extended vertically below it and carried, attached at right angles to itself, several short magnetized needles. Two Helmholtz coils were to the right and to the left of these needles. The iron rod was thus suspended free to rotate within the magnetizing coil. When the current magnetized it, it turned and in turning carried with it the aluminum wire with its attached needles. Between the iron rod and the magnetizing coil was a smaller coil with its axis vertical. This was joined to the pair of coils between which the needles hung. An alternating current flowed through the magnetizing coil. The iron rod went through a cycle of magnetization and rotated or at least tried to rotate first in one sense and then in the opposite. The small coil had an alternating current induced in it which flowed in turn through the two coils by the needles. By varying this current through a resistance in circuit it was possible to make the force exerted on the needles exactly counterbalance the force acting to make the iron rod rotate so that the system as a whole remained at rest. When this compensation is accomplished the ratio $\frac{U}{M}$ can be calculated from quantities easily measured. For iron this ratio was found to be .503 of its theoretical value, for nickel .501 and for three Heusler alloys .501. The method requires no measurement of magnetic moment, frequency or damping, and is independent of lag in magnetization, and is very accurate. Now who will discover the cause of the discrepancy?

G. F. S.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

A CINE MOTION PICTURE DENSITOMETER.[1]

By J. G. Capstaff and N. B. Green.

THIS instrument was designed to measure the small density areas met with on motion picture film which often cover not more than one-quarter of a square millimetre. It is based on the inverse square law and consists essentially of a small area light source moving in a vertical path between two small opal diffusing screens. The density to be measured is placed in contact with the upper diffusing screen. By an arrangement of mirrors, the lower diffusing screen or comparison field is arranged to give the photometric field which is viewed by means of a low-power eyepiece. An endless steel tape attached to the light source carriage is graduated in terms of "density," so that direct density readings are obtained. The intensity scale that the instrument is capable of reading is from 0 to 3.0. Although the instrument was designed for motion picture work, small density areas in negatives up to 12 × 15 inches can also be measured.

Production of Arsenic in 1923. (From Circular of the Department of the Interior.)—The refined and crude arsenic produced in the United States in 1923, according to an estimate issued by the Department of the Interior through the Geological Survey, amounted to 14,184 short tons, valued at $2,966,753, or an average value of 10½ cents a pound. This quantity is a little less than that given in the estimate made in December. The sales of refined arsenic, having a purity of 99.5 per cent. or more, amounted to 12,192 tons, and the sales of crude arsenic, having a purity of 70 to 95 per cent., amounted to 1992 short tons. Considerable crude arsenic was used in the manufacture of weed killer and distributed to eastern and western railroads for use on their rights of way. The stock of domestic arsenic at points of manufacture was small; in fact, no more than 200 tons of refined arsenic was on hand October 31st. During the first eleven months of the year 9168 short tons of white arsenic, valued at $1,695,654, were imported. Most of it came from Germany, Japan, and Mexico, but some came from Belgium, France,

* Communicated by the Director.

[1] Communication No. 194 from the Research Laboratory of the Eastman Kodak Company and published in *Photo. J.*, **64**, 97, 1924.

England, China, and Brazil. The imports of white arsenic at the eastern, Gulf, and Lake ports exceeded those at ports on the west coast. Notwithstanding the predictions of brokers early in the year, higher prices did not stimulate the accumulation of additional supplies from foreign countries. Imports of arsenic sulphide amounted to 1086 short tons, valued at $265,861. The total white arsenic bought for consumption in 1923 from domestic and foreign sources was about 22,000 tons, less than one-third of which was made into calcium arsenate, and the remainder was made into other insecticides, weed killer, and cattle dip, or used by glass manufacturers.

Eight producers in the United States reported the production of arsenic. Three smelting companies contributed 90 per cent. of the total output of arsenic. Lead smelters made fully 80 per cent. of the total smelter output of arsenic. About half the total domestic output was made from charges of regular furnace ore at the smelters, and 40 per cent. came from arsenical ores and speiss purchased. Nearly 10 per cent. of the total came from two plants that treat ore primarily for arsenic. Of the arsenic contained in ores melted in blast furnaces, probably 25 to 50 per cent. is saved. A larger recovery has been reported from plants that use direct roasting, where the fume is caught in "kitchens" and bag houses. If the future demand for arsenic warrants the expense of equipment, it may be found more profitable to treat arsenical ores directly. No new discoveries of arsenic ore were made in 1923. H. L.

Paracelsus.—An account of the work of Theophrastus Bombastus of Hohenheim, called Paracelsus, is given by EMIL AMBERG (*Am. J. Pharm.*, 1923, **95**, 840–848). Paracelsus, a forerunner of Francis Bacon, was born at Einsiedeln, Switzerland, in 1493, and died at Salzburg on September 24, 1541. He made contributions to chemistry, to medicine, and to the borderland which lies between these two great branches of knowledge. Paracelsus based his statements on experiments and reasoning, not on quotations from authorities. He eloquently defended the freedom of the press when attempts were made to forbid the publication of certain of his scientific contributions. Paracelsus, who described mercury and lead poisoning, was the first writer on occupational diseases. He attacked the polypharmacy of his day, in which as many as forty or even sixty drugs were used in a single prescription; he recommended the use of tinctures and extracts containing the active principles, instead of the administration of crude drugs. Paracelsus analyzed mineral baths and used them therapeutically, introduced laudanum and numerous chemical compounds, such as cupric sulphate, into the pharmacopœia, knew the gallic acid test for iron, and regarded zinc as an element. He practised asepsis, and was familiar with the law of similars. Paracelsus was the precursor of the modern biological chemist. J. S. H.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE CONSTITUENTS OF "CHUFA" OIL, A FATTY OIL FROM THE TUBERS OF CYPERUS ESCULENTUS LINNE.[1]

By Walter F. Baughman and George S. Jamieson.

[ABSTRACT.]

THE chemical composition of the oil obtained from domestic chufa tubers has been determined with the following results:

Glycerid of myristic acid, trace.
Glycerid of palmitic acid, 11.8 per cent.
Glycerid of stearic acid, 5.2 per cent.
Glycerid of arachidic acid, 0.5 per cent.
Glycerid of lignoceric acid, 0.3 per cent.
Glycerid of oleic acid, 73.3 per cent.
Glycerid of linolic acid, 5.9 per cent.
Non-fatty material (by difference), 3.0 per cent.

A phytosterol (m. p. 134–135° C.) was isolated from the unsaponifiable material.

The more important chemical and physical characteristics are the following:

Specific gravity 25°/25°	0.9120	
Refractive index, 20°	1.4680	
Iodin number (Hanus)	76.5	
Saponification value	191.5	
Unsaponifiable matter (per cent.)	0.6	
Acid value	15.7	
Acetyl value	10.5	
Reichert-Meissl number	0.2	
Polenske number	0.3	
Saturated acids, per cent. (observed)	18.3	(Iodin number 6.5)
Unsaturated acids, per cent. (observed)	74.6	
Saturated acids, per cent. (corrected)	17.1	
Unsaturated acids, per cent. (corrected)	75.8	
Iodin number of unsaturated acids	96.9	

* Communicated by the Chief of the Bureau.

[1] Published in *J. Agr. Research*, 26 (Oct. 13, 1923): 77.

THE SPECTROSCOPY OF THE SULPHONATED INDIGOTINS.[2]

By Walter C. Holmes.

[ABSTRACT.]

THE absorption of the pure potassium salts of the sulphonated indigotins in the visible spectrum has been measured under a variety of conditions.

Data are supplied for their spectrophotometric identification and evaluation.

A LIGNONE-DUST EXPLOSION.[3]

By Paul W. Edwards.

[ABSTRACT.]

A RECENT dust explosion in a large Eastern paper mill was probably caused by the ignition of pyrophorous carbon formed by the destructive distillation of lignone on the superheater pipes, in a lignone-dust and air mixture containing enough lignone dust to form an explosive mixture. If the steam line to the drier had not been shut off, permitting air to enter the drier, there probably would have been no explosion, for one of the essentials for a dust explosion is the suspension of the dust in air. From an economic, as well as from a dust explosion hazard standpoint, the drier should have been so designed and installed that no lignone could have escaped from the dust-collecting chamber.

THE SIMULTANEOUS PRODUCTION OF PENTOSAN ADHESIVES AND FURFURAL FROM CORNCOBS AND OAT HULLS.[4]

By Frederick B. LaForge.

[ABSTRACT.]

THE method originally worked out by the Bureau of Chemistry for the preparation of corncob adhesive consisted in heating corncobs with water in a pressure digester and concentrating the resulting solutions of gums to about 28° Bé. (about 65 per cent. solids).

[2] Published in *J. Am. Chem. Soc.*, **46** (Jan., 1924) : 208.

[3] Published in *Paper Trade J.*, Jan. 17, 1924.

[4] Published in *Ind. Eng. Chem.*, **16** (Feb., 1924) : 130.

With a temperature of about 180° C. and a heating period of about twenty-eight minutes, the yield of adhesive was 40 to 45 per cent. and the yield of furfural was 1 to 1.5 per cent., based on the air-dry weight of the cobs.

It was found that by prolonging the heating period for seven to fifteen minutes the same yield of adhesive can be obtained and at the same time the yield of furfural can be increased to about 2 per cent. without serious adverse effect on the adhesive. With further heating the adhesive is rapidly decomposed, with the formation of furfural. With a reaction period of two hours a maximum yield of furfural is obtained.

It has been shown experimentally that pentosan adhesives are especially suitable for anthracite coal briquettes.

CHEMICAL EXAMINATION OF "CHUFA," THE TUBERS OF CYPERUS ESCULENTUS LINNE.[5]

By Frederick B. Power and Victor K. Chestnut.

[ABSTRACT.]

AN examination of American-grown chufa has shown that it has essentially the same composition as that grown in Europe. Its most important constituent is a fatty oil. Another constituent which seems to be of economic interest is sucrose or cane sugar, which has been obtained in a pure crystalline state, but is accompanied in the tubers by a reducing sugar, together with gummy and albuminous material. It also contains an appreciable quantity of starch which has been obtained in the form of a perfectly white powder. An enzyme, present in only very small amount, which is capable of slowly hydrolyzing amygdalin, was also found.

The tubers did not respond to the general tests for an alkaloid, and contained no caffeine or asparagine. There was also no indication of the presence of such widely distributed simple organic bases as choline and betaine.

The Thermal Conductivity and Compressibility of Several Rocks under High Pressures. P. W. BRIDGMAN. (*Amer. Jour. Sci.*, Feb., 1924.)—"The effect of pressure on the thermal conductivity of rocks has apparently never been determined, although a knowledge of it is important in calculating the thermal equilibrium of the earth's crust." To this series of measurements Professor

[5] Published in *J. Agr. Research*, **26** (Oct. 13, 1923) : 69.

Bridgman comes after long experience in high-pressure work. He has recently determined the thermal conductivity of a number of liquids at pressures reaching to 12,000 kg. per sq. cm. He applies the same method to the rocks which now replace the liquids. "The material whose conductivity is to be measured is worked to the form of a cylindrical shell, which is slipped between an outer and an inner cylinder of copper, each of which it fits accurately. An insulated wire stretched along the axis of the inner copper cylinder carries an electric current, so that the axis is a source of heat. This heat flows out radially through the inner copper cylinder, through the shell of rock, through the outer copper cylinder, and into the surrounding temperature bath through the walls of the pressure cylinder into which the outer copper cylinder closely fits. The difference between the inner and outer copper cylinders is measured with thermocouples. From a knowledge of the heat input, the temperature difference and the geometrical configuration, the thermal conductivity may be computed." Pipestone, talc, Solenhofen limestone, diabasic basalt, pyrex glass and rock salt were examined. "In all cases the thermal conductivity is found to increase with increasing pressure, and for all the materials except pipestone the increase with pressure is linear." The percentage change of conductivity for an increase of pressure amounting to 1000 kg./cm.^{2} is calculated. This increase would be obtained by going down about two and a half miles deeper into the earth's crust. For glass, basalt and limestone the change is less than one per cent., while for talc, rock salt and pipestone it equals 1.57, 3.6 and 3 per cent., respectively. "The absolute conductivity and its pressure coefficient may either increase or decrease with rising temperature."

The results of the study of compressibilities are complicated. Hysteresis effects are considerable. "Talc and pipestone show large differences of linear compressibility in different directions. Pyrex glass has an abnormal increase of compressibility at high pressures." In no other substance has the investigator discovered an increase of compressibility as the pressure becomes greater.

With regard to the geological consequences of his measurements the author remarks: "One should be prepared in geological speculations to consider that thermal conductivity at a depth of several hundred miles may be several fold greater than the value now accepted. That the compressibility is different in different directions suggests that deep in the earth's crust where there are large differential stresses, with the probability of much greater variation with direction than those found here. It may be very far from the truth to represent the elastic behavior as that of a single homogeneous solid with two elastic constants. One must furthermore be prepared for the earth's crust to act with different effective elastic constants according as the strains are large or small, and depending on the past history." G. F. S.

NOTES FROM THE U. S. BUREAU OF MINES.*

GEORGIA CLAYS FOR RUBBER FILLERS.

By W. W. Weigel.

THE Bureau of Mines in its investigations of utilization of clays has recently completed a study of Georgia white clays with respect to their use as fillers in rubber. The purpose of this work was to determine which Georgia clays, when properly prepared, are suitable for use in rubber compounding. Samples were collected from various deposits not now used in preparing rubber filler, as well as clay from those mines which are already producing clay for use in fillers.

The samples were washed, dried, pulverized and purified in accordance with good commercial practices, and their chemical and physical properties carefully determined. Tests were then made in commercial plants on selected samples. It was found that some of the clays were suitable for use in making high-grade rubber. There was, of course, a considerable range in the properties of the different clays tested. It was shown that fineness of grain is one of the most important physical factors in the reinforcing power of the clay. Further work along this line is desirable. A paper giving more complete details is in course of publication.

SELF-RESCUER MASK APPROVED.

By A. C. Fieldner, S. H. Katz and D. A. Reynolds.

APPROVAL of a new type of safety device, a "self-rescuer," has been given by the Bureau of Mines, under the provisions of Schedule 14-A of the Bureau of Mines, which outlines the procedure for establishing a list of permissible gas-masks.

The self-rescuer is a pocket-size canister with mouthpiece directly attached, filled with granular fused calcium chloride and granular hoolamite (mixture of special copper oxide and manganese dioxide) which causes carbon monoxide in air to unite with the oxygen at ordinary temperatures forming the relatively

* Communicated by the Director.

harmless carbon dioxide. Cotton filters for removing smoke are also included and a nose clip for closing the nostrils.

The self-rescuer may enable miners to escape from atmospheres containing carbon monoxide in mines following fires or explosions, and may also safeguard workers in industries above ground where carbon monoxide may be encountered, such as around blast furnaces and metallurgical operations, or in the chemical industries. The self-rescuer is approved only for self-rescue from carbon monoxide. The Bureau of Mines does not recommend the use of the self-rescuer as a substitute for carbon monoxide gas-masks having large canisters designed to protect persons who are called upon voluntarily to meet carbon monoxide in the course of their work. Details of the tests are to be found in Serial 2591.

FLOAT-AND-SINK APPARATUS FOR TESTING COAL.

By Earl R. McMillan and Byron M. Bird.

AN improved apparatus for testing coal by the float-and-sink method was developed by the bureau in coöperative research work with the University of Washington. During the past four years this bureau and the University of Washington have been coöperating with various coal companies in the Pacific Northwest in an extensive study of coal-washing problems. Much of the valuable data resulting from this study has been obtained with the well-known float-and-sink test. This test has been known for a number of years, but its possibilities have not been thoroughly understood. A few investigators have developed apparatus and technique suitable to their needs, but these were not adapted to the conditions faced in the Northwest. Thus, the necessity arose for designing suitable equipment and working out a method of procedure or technique in carrying on the fundamental studies of coal washing by means of the float-and-sink test method.

Two separate methods and apparatus have been developed for the float-and-sink testing of coal, one for coarse sizes and the other for use with the fine sizes of coal. The practical division between coarse and fine coal for purposes of float-and-sink testing is about 20-mesh.

A float-and-sink test of a coal sample is a means of separating, in a heavy liquid, the free particles of coal from associated impuri-

ties according to differences in their respective specific gravities. When the sample is placed in the liquid, the particles of specific gravity lower than that of the liquid float; those of higher specific gravity sink. This method of separating coal from its impurities is so positive and exact that it is very much to be regretted that the cost of suitable solutions now prohibits its use in actual coal beneficiation processes.

There are two broad uses to which the float-and-sink test may be applied, first, in determining the possibilities of washing a given sample of coal; second, in measuring the effectiveness of the separation obtained by washing. Further details are given in Serials 2570 and 2586.

A Sensitive Detector for X-rays. H. BEHNKEN, G. JAECKEL and W. KUTZNER. (*Zeits. f. Phys.*, Dec. 22, 1923.)—Geiger, in 1913, showed that a fine point, kept negatively charged, experienced a sharp discharge shock when a beta particle passed in the vicinity. As X-rays set free electrons when they fall on matter, it seemed likely that such a point could be used to detect the presence of X-rays. This proved to be true. A beam of X-rays one mm. in diameter emitted from a tube with a current of .5 milliampere was found to give an effect 10 m. from the source. Only one-billionth of the total radiation reached the point, the power there being about 10^{-11} watt. In another instance one c.c. of paraffin was placed 1 m. from a Coolidge tube. To one side of the paraffin block was located the point within a chamber. X-radiation diffused by the block fell on the point and produced a series of changes of charge that were made visible by a string galvanometer or other suitable device. The number of impulses per minute was found closely proportional to the current in the tube. The authors feel that they have developed a method of value for research. G. F. S.

The Radiation from the Oxides of Aluminum and Magnesium. F. HENNING and W. HEUSE. (*Zeits. f. Phys.*, Dec. 17, 1923.)—Few experimental data on the radiation of solid, transparent bodies can be found and equally little is known concerning the change of their emissive power with temperature. "The evidence of the eye shows that a glass rod in a blast flame emits more light than would be expected from Kirchhoff's law in consideration of its small absorption at ordinary temperatures. However, in the case of glass the relations of radiation are complicated by the constant presence of the sodium flame, the light from which is reflected again and again before it makes its escape from the interior of the glass. A glass disc in a blast flame emits practically no light at right angles to its surface, but does

emit to a considerable extent at the edges. As most kinds of glass soften at temperatures at which a black body emits but little radiation, this substance drops out of consideration when the radiation of transparent solids is concerned. A rod made of fused quartz acts in the Bunsen flame like ordinary glass. If, however, one looks along the axis of a quartz cylinder that has ends ground flat, there is no greater emission of light than from the non-luminous flame and the black temperature of the cylinder observed thus cannot be measured by an optical pyrometer. Similar results can be obtained with synthetic sapphire, aluminum oxide. Glass, quartz and synthetic sapphire emit no visible radiations." The comportment of synthetic rubies, consisting chiefly of aluminum oxide with a little chromium oxide, is different. At room temperature this is red with a bit of blue in it. When it is heated up and observed against a white background, it becomes in succession reddish-brown, gray and finally glows with yellow light. "Had no change in the character of the light emitted been caused by the elevation of temperature, we would have expected the ruby to emit greenish light."

At −100° C. the ruby showed a sharply marked maximum of light absorption in the green and four distinct absorption lines, two in the yellow and the others in the blue. When the stone was warmed up to room temperature the yellow lines could no longer be found, but the blue lines remained. The maximum of absorption had shifted a trifle toward the red end of the spectrum. As the temperature rose still further the position of the maximum of absorption continued to travel toward the red. At 1100° the absorption for the green is about the same as at room temperature, but for all other wave-lengths observed between the green and the ultra-red the absorption has greatly increased and in such a way that the nearer the wave-length to the red the greater the increase has been. As a result of this change at the high temperature the ruby transmits all colors of the visible spectrum about equally well. The emissive power of the ruby remained constant only for the shortest wave-length observed. For longer wave-lengths the power increased with rising temperature and all the more rapidly the greater the wave-length was. At 1100° a portion of the ruby 9 mm. thick acted like a gray body so far as the visible spectrum was concerned and possessed an emissive power of .8. In the ultra-red both the artificial ruby and sapphire have strong absorption bands to which is due the major part of their radiation. This is about the same for both. The exceedingly white magnesium oxide, which reflects at ordinary temperature almost all the visible radiation incident upon it, even at 1200°, has an emissive power of only .02 for the visible parts of the spectrum. Ordinary magnesia was found to have a power of .15. The pure oxide at 1150° has an emissive power of more than .3 for wave-lengths greater than 4μ and emits 15 per cent. as much radiant energy of all kinds as a black body.

G. F. S.

THE FRANKLIN INSTITUTE.

(Proceedings of Stated Meeting held Wednesday, March 19, 1924.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 19, 1924.

MR. WM. C. L. EGLIN, President, *in the Chair.*

The Board of Managers submitted their report. The report recorded the election of the following Non-resident Members:

Carl W. Badenhausen, M.E.,
Short Hills,
New Jersey.

John J. Caton, B.S., M.A.,
Consulting Engineer,
321 Mercer Street,
Phillipsburg, New Jersey.

Sherman M. Fairchild, Esq.,
President, Fairchild Aerial Camera Corporation,
136 West Fifty-second Street,
New York City.

Hans Hinrichs, Esq.,
President, The Hans Hinrichs Chemical Corporation,
227 Fulton Street,
New York City.

Rowland S. Potter, Esq.,
Vice-president, American Photo Products Company,
Verona, New Jersey.

Benedict Tikhonovitch, Esq.,
Electrical Engineer,
The New York Edison Company,
New York City;

and additions to the Library by gift, 59 volumes, 22 pamphlets, by purchase 32 volumes and 3 pamphlets.

The Chairman then announced that final action would be taken on the following resolutions to amend the By-Laws as recommended by the Board of Managers to the Institute at its Stated Meeting of February 20th last:

Resolved, That Article III—Members, By-Laws of the Institute—be amended by inserting after Section 3, Section 4. There shall be in addition to present classes of membership a class of membership known as contributing membership, which shall consist of firms, corporations, associations, or individuals, who shall pay an annual sum of $300, with the privilege of nominating to the Board of Managers members of their staffs or others engaged or interested in scientific pursuits or in the application of

physical discovery in the industries, in number to be determined by the Board of Managers.

Resolved Further, That present sections of Article III—Members, numbered 4 to 12 inclusive, be numbered 5 to 13 inclusive.

On motion of Doctor Hoadley, duly seconded, these resolutions were unanimously adopted.

The Chairman then introduced Eskil Berg, E.E., M.E., of the Consulting Engineering Department, General Electric Company, Schenectady, New York, who presented the paper of the evening on "Pressure, Superheat and Reheating as Affecting Power Plant Economy."

The speaker invited attention to several of the largest modern power plants in this country and abroad which have recently adopted working pressures up to five hundred and fifty pounds with reheating and steam extraction. He said that steam boilers and turbines are being built for one thousand to twelve hundred pounds pressure and a maximum temperature of seven hundred and fifty degrees. He also discussed the economies in power generation to be effected by the use of such higher pressures and temperatures.

After the address of the evening Mr. John L. Cox, Assistant to the President, the Midvale Steel Company, showed a number of lantern slides and described the manufacture of forged steel steam drums for boilers designed for twelve hundred pounds pressure. Messrs. H. P. Liversidge, Charles Penrose and M. M. Price discussed at some length the matter of economies referred to by the speaker.

On motion of Mr. Penrose a rising vote of thanks was extended to the speaker and the meeting adjourned.

R. B. OWENS, *Secretary.*

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, March 5, 1924.)

HALL OF THE INSTITUTE,
PHILADELPHIA, March 5, 1924.

DR. JAMES BARNES *in the Chair.*

The following reports were presented for first reading:

No. 2779: Locomotive Feed Water Heater.
No. 2824: Literature.

R. B. OWENS, *Secretary.*

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, March 12, 1924.)

NON-RESIDENT MEMBERS.

CARL W. BADENHAUSEN, M.E., Short Hills, New Jersey.

JOHN J. CATON, B.S., M.A., Consulting Engineer, 321 Mercer Street, Phillipsburg, New Jersey.

SHERMAN M. FAIRCHILD, Esquire, Engineer, President, Fairchild Aerial Camera Corporation, 136 West Fifty-second Street, New York City, New York.

HANS HINRICHS, Esquire, President, The Hans Hinrichs Chemical Corporation, 227 Fulton Street, New York City, New York.

ROWLAND S. POTTER, Esquire, Technical Director, Vice-president, American Photo Products Company, Verona, New Jersey.

BENEDICT TIKHONOVITCH, Esquire, Electrical Engineer, The New York Edison Company, New York City, New York.

CHANGES OF ADDRESS.

DR. EDWARD V. D'INVILLIERS, 121 North Broad Street, Philadelphia, Pennsylvania.

MR. MALCOLM R. MACLEAN, Rural Felicity, Savannah, Georgia.

NECROLOGY.

Mr. Theodore W. Cramp, 816 Commercial Trust Building, Philadelphia, Pennsylvania.

LIBRARY NOTES.

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BOOK REVIEWS.

CORROSION TESTS AND MATERIALS OF CONSTRUCTION FOR CHEMICAL ENGINEERING APPARATI. By W. S. Calcott, J. C. Whetzel and H. F. Whittaker. Published by the American Institute of Chemical Engineers. vi–182 pages, 8vo. New York, D. Van Nostrand Company, 1923. Price, $3 net.

The chemistry and physics of corrosion are among the most important problems in chemical engineering. The enormous development of the chemical industries in the last half century, not only in extent but in variety, has brought to works-chemists many serious problems. In ordinary laboratory work, glass and platinum furnish materials sufficiently resisting to almost all corrosive substances employed, but large installations cannot use such materials and the common metals are subject to many forms of corrosion. It appears that the general question has been especially studied in recent years by English-speaking chemists. A recent issue of the *Jour. Pharm. Chim.* ([7], 1924, **29**, 9) contains an article by Lasausse, summarizing the work done by American and British investigators. An extensive literature has already been developed. The book in hand is largely made up of data obtained in the Jackson laboratory of the duPont Company and acknowledgments are formally made to the officers of that company for permission to publish. The hope is expressed that other large corporations will be moved to do likewise. Messrs. Calcott and Whetzel are chemical engineers in the Jackson laboratory; Mr. Whittaker, chemical engineer in the National Research Council. The first half of the book sets forth in great detail the data obtained in the Jackson laboratory; the latter half is devoted to a presentation by Whittaker of the best materials for construction of chemical apparatus. Such materials are, of course, different

for different procedures. Acids and alkalies have very different action on a given substance. The abundance of iron and also good supply of copper, lead and zinc have caused these to be generally applied to the construction of large apparatus, but though they differ considerably in their susceptibilities to corrosion, they are all not as resistant as desired. The discovery of methods of extracting metals that cannot be obtained by the older furnace operations, has added considerably to the available materials for chemical work, and the supply has been much increased by the invention of many alloys, some of which have remarkable resistant qualities. Chemical engineering is by no means concerned with apparatus of metal, resistance to heat and shock constitutes an important problem. Much has been done of late years in the study of refractories, but the subject is, of course, not considered in the work in hand. The progress made in substituting the metals of newer availability for those long in use is set forth in Whittaker's paper. Aluminum is now replacing copper in the distillation of acetic acid, except when formic acid is present. Very minute amounts of formic acid will rapidly corrode aluminum. This metal serves best for distillations and concentrations of the rather strong acetic acid. Nickel suits very well, but until lately has only been obtainable in cast form. It is now, however, capable of being worked like copper. Silver is used when very high-grade products are desired. A curious fact is noted that 60 per cent. hydrofluoric acid can be shipped in steel drums that have been passivified, which is done by exposing them to the action of the acid under special conditions. Passivity in iron and steel has been long known and many years ago was applied in the construction of a galvanic cell, in which a cast iron cell was the negative metal, in contact with a depolarizing solution of strong nitric and strong sulphuric acids. As long as the acid mixture maintained a certain strength, no corrosion occurred on the iron, but when diluted, active corrosion took place.

Many curious facts are given in the work, and much valuable practical information is brought out in the discussions. The subject is a vast one and offers a field not only for research, but for exercise of inventive talent. The information is presented largely in tabular form, but extensive descriptions are given. The material thus collected is of great value to industrial chemists.

HENRY LEFFMANN.

CLOUDS AND SMOKES. The properties of disperse systems in gases and their practical applications. By William E. Gibbs, D.Sc. With a foreword by Sir Oliver Lodge. xiii–240 pages, illustrations, 8vo. Philadelphia, P. Blakiston's Son and Company, 1924.

Doctor Gibbs, who is chief chemist to the Salt Union, Ltd., of Liverpool, England, has set forth in this book a highly interesting and valuable study of common atmospheric phenomena, interpreted in the light of the modern theories of physical chemistry. Clouds and smokes have been familiar to human beings since they had a capacity to appreciate intelligently their environment. As with many other natural phenomena, primitive man interpreted them in a more or less mystical light. The dawn was personified as Aurora, and the rosy tint that is generally seen at sunrise was spoken of as a mantle or as spread fingers

The eighth book of the Iliad opens with the remark that "krokopeplos eos," "rosy-mantled dawn," had spread over the earth. The gods and goddesses, having had a good night's rest, were called in solemn council by Zeus.

In addition to the presentation of the theories of the formation of all forms of suspensions of small particles in the air, a large amount of practical information is given. Dust explosions, smoke nuisances, fogs and mists are described and explained. The term "aerosol" is introduced to designate all disperse systems in which a disperse medium is a gas or vapor. It then becomes analogous to "hydrosol." Systems in which particles are too large to acquire Brownian movements are termed "clouds," and more highly disperse systems are termed "smokes." He adds a third class "dusts," in which the particles are larger than 10^{-3} cm. These settle with accelerating velocity in still air. Particles which range from 10^{-5} to 10^{-7} cm. show the Brownian movement actively, and do not settle in still air. A table of industrial dusts, clouds and smokes is given and it is interesting to note that the particles of tobacco smoke are the finest mentioned. Whether this fact is available for or against the use of the weed cannot be said.

The chemical composition of atmospheric dust is a matter of general, as well as sanitary, interest. In the neighborhood of industrial areas, of course, the products of the incomplete combustion of coal constitute a large percentage, mostly soot particles ranging between 0.25 micron and 1 micron, with tarry oils and very fine particles of ash. In this connection it is worth while to note that a large proportion of finely divided ash will be thrown into the atmosphere if powdered fuel comes into extensive use, and this fact, indeed, constitutes one of the objections urged against that form of firing. The real remedy for the smoke and ash nuisance is the employment either of oil or of gases obtained by the distillation or other treatment of coal. A systematic study of the suspended matter in the air has been carried on in Great Britain for the past eight years. In certain types of warm, dry weather, a blue haze is found all over England. This cannot be due to water-vapor but is caused by smoke particles, about half a micron in diameter, that have been carried from industrial centres. Such particles are often carried very far. The occurrence of haze may, however, not be due to smoke from industrial plants. Forest fires, pollen, salt spray and volcanic and cosmic dust can cause haze. The eruption at the island of Krakatoa in 1883 caused an immense mass of dust to be distributed through the upper atmosphere, and peculiar red sunsets were noted for some time in many parts of the world. At Algarve, in Portugal, a blue haze was found to be due to sodium chloride. Dust from sleet and hail, and even from clouds and rain, has been examined spectroscopically and found to contain iron, nickel, calcium, copper and lead. The amount of carbonaceous matter is small.

Much information is given concerning the causes and condition of dust explosions. Sugar and starch are among the most powerful explosives when mixed with the proper proportion of air. The book is of value to the sanitarian as well as to the meteorologist, and possesses much interest for the general reader.

HENRY LEFFMANN.

ALLEN'S COMMERCIAL ORGANIC ANALYSIS. Fifth edition, Vol. i, revised, and in part rewritten. Edited by Samuel S. Sadtler, Elbert C. Lathrop, and C. Ainsworth Mitchell, assisted by special contributors. viii–796 pages, 105 illustrations, 8vo. Philadelphia, P. Blakiston's Son and Company. Price, $7.50.

Allen's "Commercial Organic Analysis" appeared about the last quarter of last century, and was at once received with great joy by practising chemists everywhere. It brought into convenient compass the processes of analysis of the many substances that had begun to be commercial articles in consequence of the rapid development of organic chemistry. It took at once the front rank among laboratory manuals, a position which it has ever since maintained. Though its author has long since passed away, the general form, scope and method of the work are maintained. It has, of course, increased enormously in extent, and several editions have appeared. The present volume initiates a new edition which will doubtless be several years in completion, in fact some of the manuscript was ready several years before being published, which accounts for some staleness in the text. Progress in applied chemistry is so rapid that it is impossible for any work to keep entirely up with the development. This fact is illustrated by the condition of the section on the detection of methanol (methyl alcohol) in the presence of ethanol. This procedure has become of great importance in the United States on account of the liability of denatured alcohol to be used in more or less modified form as a substitute for common alcohol. LaWall (*Trans. Wagner Free Inst. Sci.*, Philadelphia, **10**, reprinted in *Amer. Jour. Pharm.*, 1923, **95**) has reported the results of a careful examination of the U. S. P. test, and has introduced some modifications which make the method entirely satisfactory and quite convenient. Considerable experience with the test by the reviewer has shown its value, and it seems unnecessary to employ any other in ordinary cases.

The present volume is entirely written by the collaborators, the editors contributing only general work, notes and index. The work will maintain its hold on the practising analysis and works-chemists, but it is to be hoped that the succeeding volumes will appear with less delay after the manuscripts are in hand, for it is unjust to contributors and misleading to users to withhold articles for several years after they have been prepared. Contributors under such circumstances are liable to be charged with lack of up-to-date information.

In this connection it is deemed proper to refer to a somewhat unjust review of the book that has recently appeared anonymously in the *Journal of the American Medical Association*. Stress is laid on the fact that the book is of comparatively little use to the medical chemist, but the work was never intended for such purpose. It is fundamentally a manual of commercial organic analysis, and while in many points, owing to broad scope of the subject, items of physiologic or pathologic chemistry are brought in, the major portion of clinical and pathological analysis is left out. The *J. A. M. A.* reviewer makes a point of the fact that only nine pages are devoted to "urine analysis," but this portion (which is actually only eight pages) is devoted to the detection of carbohydrates, and is surely a sufficient amount for this class of substances. A mild criticism can be made of this section that the title in the table of contents

"Urine Analysis" is misleading, but a very serious error is that at the close of the section the user of the book is referred for further information to "Analyse des Harns." What book is this? No author or publisher is mentioned, but much worse is the fact that reference is made to a German work when there is abundant literature in English on all the details of urine analysis.

The initial section—on analytic methods, chemical and physical—has been left almost unchanged from the form contributed by Mr. Davis in 1909. Much advance in the design and construction of apparatus has been made since that date, and it seems that this section should have been submitted to much more extensive revision. It is a question, however, whether it might not have been omitted altogether. The book is not a student's manual. Those who use it will be trained in the general methods of laboratory work and will have before them the modern apparatus with all necessary directions.

A re-issue of the "Commercial Organic Analysis" will be welcomed by all practising and works-chemists. The original plan of the book as Mr. Allen issued it has, of course, suffered some modifications in detail, but his influence is still active. The great expansion of the field of industrial organic chemistry and the many problems that have arisen have necessitated the employment of many contributors, but editorial supervision will prevent any disagreements, and proportion the attention given to each class of topics in accordance with the importance thereof.

The publisher has issued the work in the substantial and convenient form that is characteristic of the house and the fifth edition will take rank with its predecessors in the fore-front of laboratory guides.

HENRY LEFFMANN.

PULVERIZED FUEL. A practical handbook. By W. Francis Goodrich, M.B.E. xi–215 pages, 12mo, 88 illustrations and 16 tables. London, Charles Griffin and Company; Philadelphia, J. B. Lippincott Company, 1924.

The application of coal in pulverized form has been extensively studied by fuel engineers for a long while. Undoubtedly the method possesses great advantages from the points of view of economy and convenience. One difficulty has been the liability to spontaneous combustion. Its use in the United States is extending, the author stating in the preface that over thirty million tons are now used annually. An item of sanitary importance is the prevention of smoke, but on the other hand, the finely divided ash is necessarily expelled in large amount from the stack, and may constitute a serious nuisance. This objection may, however, be overcome by simple means. It is true also that the discharge of fine material occurs with other methods of firing; according to the author of this book, mechanical stokers are also offenders. Problems of construction of the apparatus for preparing, storing and applying the powdered fuel have been energetically attacked, and while complete solution has not yet been obtained, success is certain. The proposal to use powdered fuel was made at an early date probably, but in 1831, J. S. Dawes was granted a patent in Great Britain for an apparatus for using any solid combustible in powdered form. The book gives interesting information concerning the early developments of the methods and also much matter relating to United States practice, for it seems that this country is in advance of England in this respect.

The book is timely, for the fuel question is becoming very acute, not only from the point of view of increasing expense of mining and transporting, but from the increasing nuisance from smoke. The finely divided ash will be, of course, if in great quantity, an annoyance, but it will be at any rate less disfiguring to the neighborhood. The book is largely illustrated and sets forth the present state of the industry in much detail. Two systems have been developed: The central, which is only suitable for large installations and the unit, which embodies the most direct, simplest and cheapest methods. The index does not contain any reference to the danger of spontaneous combustion, but in connection with a discussion of the hygroscopic nature of the fuel, it is stated that pulverized coal containing 0.75 per cent. of sulphur and 1 per cent. of moisture will surely ignite within a few days, and if the moisture content is over 1 per cent. and the sulphur over 4 per cent. spontaneous ignition may occur within twenty-four hours after pulverizing. In this connection attention may be called to a modification of powdered fuel which is receiving attention, the so-called colloidal fuel, consisting of powdered coal suspended in fuel oil. After all, the day may not be distant when water and sun-power will serve largely for industrial purposes and coal and oil will be burned at points at which they are found and the power transmitted by electricity.

HENRY LEFFMANN.

MODERN ELECTRO-PLATING. A guide-book for platers, works-chemists and engineers. By W. E. Hughes, B.A., D.I.C. vii–160 pages, 30 illustrations. London, Henry Froude and Hodder and Stoughton. Oxford University Press, New York, agent, 1923. Price, $5.35 net.

This book is one of the series of Oxford Technical Publications. The field which it covers is of great importance in modern life, and the methods of operating have changed greatly since the commercial development of electricity has rendered the use of currents of high amperage available. The author explains in the preface that the book is not a textbook, but a republication of a number of articles that have appeared in the publication known as *Beama*. This title is a somewhat cryptic logograph for "British Electrical and Allied Manufacturers' Association." The title has recently been changed to *World Power*, which, apart from its more familiar sound, has a sentimental significance, for it indicates that electricity is becoming more and more the motive force of industrial operations.

Plating is an ancient art, and was naturally first applied to coating the baser metals with the precious. Of the group, still often called the noble metals, only gold and silver were available in ancient times, for mercury is not adapted to such use. Formulas for coating articles with thin gold and silver leaf have come down to us from the early centuries of the era and also formulas for alloys of the baser metals to imitate gold and silver. Fire-gilding, in which an amalgam of the precious metal was used as a coating, the mercury being later driven off, was an early art. "Triple fire-gilt" was a trade term well known fifty years ago. The invention of the voltaic couple, especially the fairly constant forms of it, such as the Grove, Smee and Daniel cell, made electro-plating commercially possible and a rapid and extensive development of the industry began. The introduction of the dynamo was of great advantage,

and now that currents of different voltage and character are commercially available, the operation of electro-plating takes rank among the large-plant industries.

The book is especially designed to assist foremen-platers, works-chemists and engineers. Much that does not bear on these objects has been omitted. Metals have been chosen that are of the most importance. The omission of silver has been due to a desire to economize space, but seems to be a matter of regret, as that metal is so largely used in the industry. The treatment of the whole subject is quite elaborate, theory as well as practice being extensively considered. An unusual and pleasing frankness is exemplified in the preface, the author inviting those that do not understand the statements to inquire of him by letter. This is undoubtedly a commendable attitude, but he may find the reaction to the suggestion more active than expected.

The numerous photomicrographs of deposited films add greatly to the value and interest of the book. The metals treated are: Iron, nickel, zinc, lead, tin, chromium, copper. Special chapters are devoted to theory and practice, and the structure of electro-deposited metals. An original idea is a chapter on "Reading," which is a bibliography of important literature of the subject with comments on some of the items. The book throughout shows the originality of the author and the information given shows his extended familiarity with the subject. The progress of the industry is strikingly shown by comparing the book in hand with the small, thin volume issued by Napier in the middle of the last century. The early workers in this field would have been skeptical if told that in the future such metals as chromium and iron would be available as plating. It is true, indeed, that the author states that chromium plating has not been developed to a workshop procedure, but the step from laboratory success to industrial success is almost always accomplished, though "patient search and vigil long" may be required to attain the end.

The book is a valuable contribution to the electro-plating industry, and it is to be hoped that a second edition will be soon demanded and the author will see his way clear to include the plating by silver, gold and platinum.

HENRY LEFFMANN.

TREATISE ON GENERAL AND INDUSTRIAL ORGANIC CHEMISTRY. By Dr. Ettore Molinari. Second English edition. Translated from the third enlarged and revised Italian edition, by Thomas H. Pope, B.Sc., F.I.C. Part II, vii–441 pages, 305 illustrations, 8vo. Philadelphia, P. Blakiston's Son and Company, 1923. Price, $8 net.

This volume is paged consecutively with Part I of the organic chemistry, and contains the conclusion of the discussion of the aliphatic compounds with the cyclic series, proteins, glucosides and some other substances of uncertain or unknown composition. A section is given to coloring matters and also to textile fibres.

The general nature and value of the work have been widely and favorably known since the first translation was published. The translator is well equipped for the work and has done it well. This being the continuation of a volume, there is no introductory matter or preface, but the index, of course, covers both parts. The index is quite comprehensive. About three-quarters of a page are

devoted to the vitamins, probably quite enough considering the field to which the book is devoted and the limited knowledge as yet of these substances. A very large amount of information is presented in a compact and convenient form. The original text, having passed through the hands of a British chemist of experience and ability, has necessarily been somewhat better adapted to English-speaking workers, though it is evident that the author has a wide acquaintance with the subject and has produced a book of value and excellence.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 176, A Constant Pressure Bomb, by F. E. Stevens. 8 pages, illustrations, quarto. Washington, Government Printing Office, 1923.

This report describes a new optical method of unusual simplicity and good accuracy suitable to the study of the kinetics of explosive gaseous reactions; it deals with a part of an investigation of the rates of explosive gaseous reactions being carried out at the Bureau of Standards at the request of and with the support of the National Advisory Committee for Aeronautics.

The device is the complement of the spherical bomb of constant volume, and extends the applicability of the relationship, $pv = nRT$ for gaseous equilibrium conditions, to the use of both factors p and v.

The method substitutes for the mechanical complications of a manometer placed at some distance from the seat of reaction the possibility of allowing the radiant effects of the reaction to record themselves directly upon a sensitive film.

It is possible the device may be of use in the study of the photo-electric effects of radiation.

The method makes possible a greater precision in the measurement of normal flame velocities than was previously possible.

An application of the method in the investigation of the relationship between flame velocity and the concentration of the reacting components, for the simple reaction $2CO + O_2 \rightleftarrows 2CO_2$, shows that the equation $k = \frac{s}{C_{co}^2 \, Co_2}$ describes the reaction.

An approximate analysis shows that the increase of pressure and density ahead of the flame is negligible until the velocity of the flame approaches that of sound.

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Foibles and Fallacies of Science. An account of celebrated scientific vagaries, by Daniel W. Hering, C.E., Ph.D., LL.D., Professor Emeritus of Physics, New York University. 294 pages, illustrations, 8vo. New York, D. Van Nostrand Company, 1924. Price, $2.50.

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